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POTEnCIA technical peer-review

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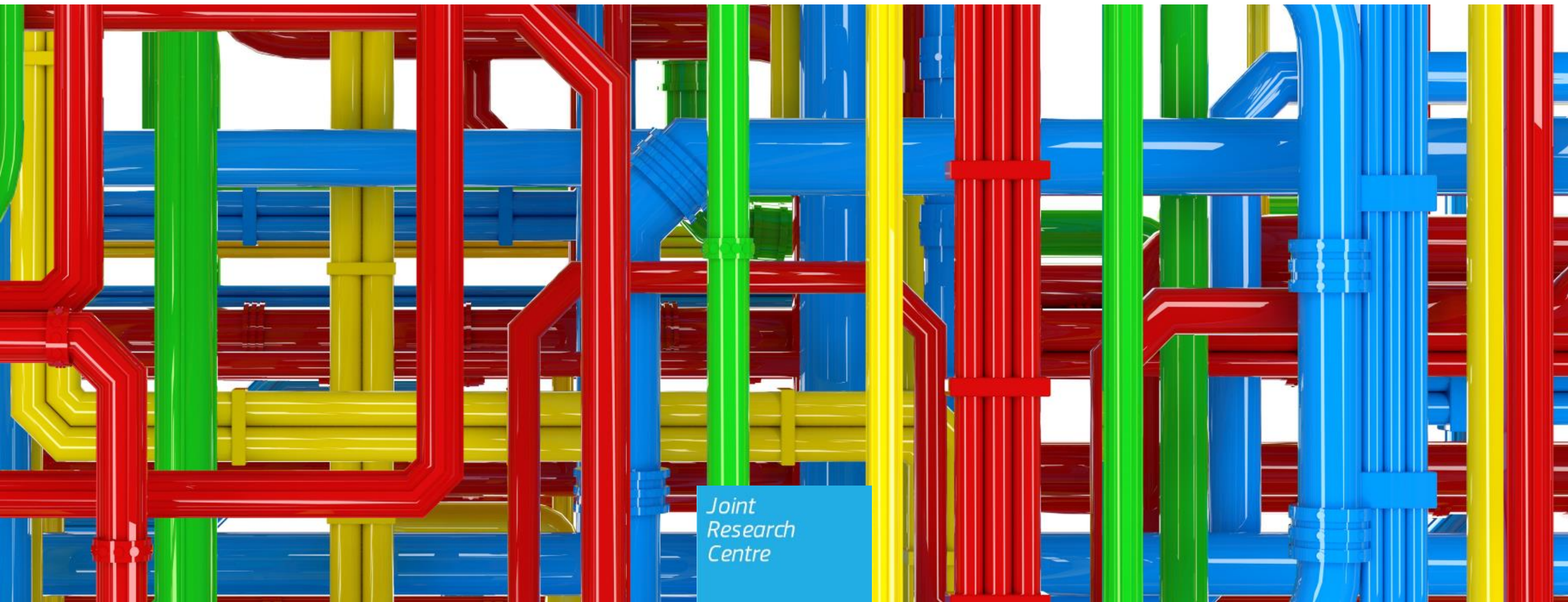
2017



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JRC108360

Seville: European Commission, 2017

How to cite this report: SORIA RAMIREZ A., POTEnCIA technical peer-review – Related documents, European Commission, Seville, 2017, JRC108360

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1 Introduction

POTEnCIA (Policy Oriented Tool for Energy and Climate Change Impact Assessment) is a modelling tool for the EU energy system, designed to assess the impacts of alternative energy and climate policy options on the energy sector under different hypotheses about surrounding conditions within the energy markets. It has been developed by JRC-Seville with the support of the Commission services responsible for Energy, Climate Action and Transport and Mobility.

The modelling tool underwent a technical peer review exercise, which was initiated by a workshop on March, 1&2, 2016. The peer-reviewing panel consisted of:

Leen Hordijk (Chairman)

Patrick Criqui (EDDEN LAB, University Grenoble Alpes)

Keywan Riahi (International Institute for Applied Systems Analysis - IIASA)

Christian von Hirschhausen (German Institute for Economic Research - DIW Berlin)

Peter Taylor (Secretary; Centre for Integrated Energy Research - University of Leeds)

The purpose of the peer reviewing exercise was to assess the model's capability to provide the answers to questions it has been conceived to address, and therefore to help the JRC to improve the tool as a policy supporting instrument. In particular, the review focused on the following aspects:

1. Validity of the methodological approach
    a. model definition and formulation across energy system sectors
    b. model capacity to capture challenges faced by the energy sector
2. Model capacity to adequately address EC policy analysis needs (including impact assessments)
3. Adequacy and validity of the data used in the model (data sources and data decomposition)
4. Robustness and validity of the scenario building approach/process (interaction with other modelling tools/involvement of stakeholders)
5. Transparency of model and data

This document contains the finding of the peer-reviewing panel as submitted to the JRC on March, 15, 2017.

It further includes the reply provided by the JRC to the peer-review panel.

In addition, it documents the presentations given at the meeting on March, 1, 2016 on the POTEnCIA energy model and the JRC-IDEES (Integrated Database on the European Energy Sector). The POTEnCIA model description (version 0.9) published prior to the review exercise can be downloaded at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC100638/jrc100638_potencia%20model%20description%20-%20version%200.9.pdf

2 International Review of the POTEnCIA Energy Model - Report of the 2016 Review Panel

International Review of the POTEnCIA Energy Model

Report of the 2016 Review Panel

Leen Hordijk (Chairman), Patrick Criqui, Keywan Riahi,
Peter Taylor and Christian von Hirschhausen

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1. Introduction

This report describes the findings of an international peer review of the new JRC energy modelling tool POTEnCIA (Policy Oriented Tool for Energy and Climate Change Impact Assessment). The development of POTEnCIA was carried out by the JRC's Institute for Prospective Technological Studies (IPTS) in the unit Economics of Climate Change, Energy and Transport (ECCET), located in Seville (Spain).

1.1 Motivation for developing POTEnCIA

The European energy sector has entered a phase of rapid and substantial changes. Key challenges facing the sector include: environmental issues, including the need for ambitious greenhouse gas emission reductions; increasing concerns about energy security of supply; the need to achieve more rational and efficient use of energy; market transformations such as the liberalisation of European energy supply and the creation of a single European energy market; and the advent of new (and often variable) power generation technologies that are changing the simplistic industrial pattern of centralised producers and decentralised consumers.

The JRC have designed POTEnCIA to assess the impacts of alternative energy and climate policies on the energy sector, under different hypotheses about surrounding conditions within the energy markets. The model covers each EU Member State separately, while also being able to address the EU28 energy system as a whole. POTEnCIA typically models the period to the year 2050 in annual steps (but longer timeframes are possible). To achieve this, POTEnCIA aims to: represent accurately novel technologies on both the supply and demand side; capture the implications of moving a significant portion of generation capacity to decentralised production and the possible impacts on networks; include a high level of technological disaggregation and represent appropriately technology dynamics for both energy consumers and suppliers under different policy regimes; and explicitly address premature replacement of technologies and the corresponding stranded investment costs.

Further details about the model are available at https://ec.europa.eu/jrc/en/potencia.

1.2 The nature and scope of the peer review

The Panel agreed with the JRC that the review should examine the following aspects:

1. Validity of the methodological approach.
    a. model definition and formulation across energy system sectors.
    b. model capacity to capture challenges faced by the energy sector.

2. Model capacity to adequately address European Commission policy analysis needs (including impact assessments).

3. Adequacy and validity of the data used in the model (data sources and data decomposition).

4. Robustness and validity of the scenario building approach/process (interaction with other modelling tools/involvement of stakeholders).

5. Transparency of the model and data.

2. Main messages

1. General appreciation of relevance of project and achievements

The overall modelling approach used by the POTEnCIA energy model is appropriate, being strongly rooted in the simulation paradigm and so able to represent energy system dynamics. The model is also suitable for the analysis of the impacts of energy and climate policy measures due to its detailed description of the energy sectors and of the behaviour of the agents/consumption units. The concept of the "representative economic agent", which allows a decoupling between the stock of energy supply and demand technologies and their utilisation, is an interesting feature. The approach chosen for many of the sectors of defining "market acceptance factors" generally succeeds well in explaining observed energy shares (while taking into account national differences), but could run the risk of biasing future energy shares by relying too strongly on past behaviour. This could be a particular danger in sectors where cases of disruptive innovation are likely.

2. IDEES – value and need for free public access

The JRC-Integrated Database of the European Energy Sector (IDEES) is a very positive development to support the implementation, reliability and transparency of the POTEnCIA model. The database is both an essential input to the model and a valuable additional resource that can become a reference for quantitative energy-related research for the wider policy-scenario modelling community in Europe and beyond. The current update of the database from the year 2010 (currently used) to 2014 should be completed as soon as possible to ensure that it reflects the latest available information. The panel strongly supports the plans to make IDEES a free public database.

3. Transparency, understandability, credibility - open access nature of model

The success of POTEnCIA, in both the academic and policy worlds, will partly depend on it being available in a transparent and accessible form, including having clear and in-depth documentation. To help with the communication of scenario results, the Panel believes that further effort is needed to define a format for model results that includes, not only the full details currently available, but a structured intermediate level of inputs and results, with the definition of policy relevant indicators in compact dashboards. Additionally, it is not clear why a fully open source version of the code is not envisaged, with the JRC being able to maintain its patronage over the model and the process, but potentially benefiting from a wide diffusion of POTEnCIA in the modelling world. Whatever final decision is made in this respect, it will be important to define a precise protocol for communication with potential users and for the accessibility of the code and data.

4. Strengths of model – core role but linking to other models – heart of a framework to analyse impacts of energy and climate change policies

The model has a number of strengths for policy analysis, including the ability to explore lock-in and path dependency through detailed technological representation of the energy demand sectors. The treatment of the power sector is more aggregated than the demand sectors, with only seven time slices, and uses the concept of "market acceptance factors" to determine the mix of electricity generating technologies. The Panel is concerned that this "conservative" approach may limit the ability of POTEnCIA to model the kind of disruptive changes that are already occurring. The model is currently very much focused on modelling CO_2 emissions, but energy models also need to address air pollution, energy security and affordability challenges, as well as the role of energy in other sustainable development objectives (food, energy, water, land nexus). This calls for a strategy of 1) expanding POTEnCIA in order to represent better social heterogeneity and 2) linking it to other models e.g. to understand possible trade-offs (or synergies) between energy and other issues.

5. Potential of the model - establishing strategies for dialogues between EC and MS

The capability of POTEnCIA to model a wide range of different scenarios has not yet been proven, although this is an important element of the utility of the model for the policymaking process. Before publication of the model, the Panel suggests running a small set of scenarios of different policy stringencies, showing the potential use of the model. These scenarios should explore different sensitivities for the cost, performance and availability of the various supply and demand-side technologies. They should also reflect variety, for example by including a technological setting with a low share of nuclear energy, and the absence of carbon capture and storage.

3. Detailed comments

1. Validity of the methodological approach
a. model definition and formulation across energy system sectors

1. The POTEnCIA model is a partial equilibrium energy system model that considers behavioural factors, which can be country specific. This allows the model to explain some of the differences that are observed across sectors and agents, and thus at least partially moves away from the concept of "economically optimal" market solutions. Thus, the model has the potential to be a useful complement to existing EU energy models, while allowing for a dialogue between the JRC modelling team and national experts from Member States.
2. The model definition is appropriate for the analysis of the impacts of energy and climate mitigation policy measures due to its detailed description of the different energy sectors and of the (current) behaviour of the agents/consumption units.
3. The overall modelling approach is good and strongly rooted in the simulation paradigm in order to represent energy system dynamics. This in turn allows policy benefits, as well as costs, to be represented. The trade-off with the method, however, is the perceived lack of causality between inputs and outputs, which potentially runs the risk of leading to a "black-box" if the relationships are not documented well.
4. The concept of the representative economic agent, which allows for a decoupling between the stock of energy supply and demand technologies and their utilisation, is an interesting feature. However, an alternative name such as "representative consumption unit" may better communicate the concept.
5. In addition, further work is needed to represent better the salient (social) heterogeneities of different agents that determine different behaviours. This is particularly important in key sectors where they play the biggest role e.g. the housing or transport sectors. Collaborations between the JRC and leading institutions might help foster quick progress and will be critical to understand the "enabling factors" of policy success in areas where non-economic barriers (and opportunities) play a significant role (e.g. vehicle choice).
6. The approach chosen for many of the sectors of defining "market acceptance factors" is generally successful in explaining the observed energy shares (through multinomial logit distributions). However, there is a risk that if the market acceptance factors are kept constant over time then the model will simply forecast past energy trends into the future. This could be a particular danger in sectors where cases of disruptive innovation are likely (e.g. the power sector). For the demand sectors, the model structure allows these market acceptance factors to be modified endogenously in future years in response to changes in economic conditions and the introduction of policies. For the power sector, any changes need to be exogenously defined. For all sectors, particular attention should be given to making sure that the development of the market acceptance factors adequately reflects the impacts of all drivers which can affect technology acceptance. Fully endogenising this feature will require some future model enhancements e.g. to link the acceptance of electric vehicles to developments in the re-charging infrastructure.
7. There is a difference between the quite detailed level at which the demand side in various sectors is considered, and the relatively aggregated approach used to address the power sector (which has only seven load slices for one entire year). Given the limitations of the time resolution

and the conservative approach (based on "market acceptance factors") that more or less maintains the structure of the 2010 mix based on conventional energy sources, the current implementation of the power sector is not capable of anticipating the kind of disruptive changes that are already occurring e.g. the future working of a largely renewables-based system, where ramping capabilities and the use of various storage technologies (electrochemical, power-to-heat, etc.) play a central role. This dilemma could be resolved by sequentially running a longer-term optimisation model for power sector investments (at the European and the Member State level) and then updating the "market acceptance factors" in POTEnCIA through backward induction.

8. The detailed treatment of capital vintages can provide a good representation of inertia in the transformation of the energy system and it also allows technical change to be endogenised within key demand sectors. The model is well suited to explore lock-in and path dependency in the various energy demand sectors, stemming from incremental technological and structural changes. The exploration of radical technological changes (and innovation) will need to rely on appropriate scenario formulations (e.g. sensitivity analyses for technology availability).

b. model capacity to capture challenges faced by the energy sector

1. The model capacity is adequate, using a forward advancing approach to develop future scenarios that start from the current energy situation. However, some very stringent scenarios, in the post COP21 context, may require elements of a backcasting approach in order to account for path dependencies.
2. As the model is extremely detailed in terms of sectoral decomposition and numbers of parameters, it would be helpful to develop a synthetic set of indicators for different elements that allow the economic consistency at a sector level to be checked, e.g. the sufficiency of investment requirements and capabilities, and the impact of total energy expenses on households' income or industrial sectors' activity.
3. The model is currently very much focused on CO_2 emissions. For climate policy impact assessment it also will be important to include other greenhouse gas emissions. The impact of climate policies on air pollutant emissions should be analysed by linking to the GAINS model.
4. Energy models need to address not only climate change, but also energy security and affordability challenges, as well as the role of energy in other sustainable development objectives (e.g. the energy, food, water, land nexus). A strategy for linking POTEnCIA to agricultural, as well as hydrological models, is needed in order to understand possible trade-offs (or synergies) between the energy system and these other sectors.
5. Better representation of the geopolitics which are driving EU security policies/strategies will require more elaborate representation of global developments.

2. Model capacity to adequately address EC policy analysis needs (including impact assessments)

1. The model capacity and the adequacy of the approach differs from sector to sector.
    - There is good representation of drivers of change, as well as policy leverages, in the industry sector.
    - The residential and commercial sectors have detailed technology representation. However, the current representation lacks the social heterogeneity that would be needed to understand better the implications of policies for different households characterised by

  different vulnerabilities e.g. affordability, resilience and security. This will require a better representation of social and human agents (beyond technology and Member States' differences, including a better representation of the poor and vulnerable within the different countries).
  - In the transport sector, a major driver for policies and their effectiveness is the development of associated infrastructures with their impacts on the behaviour of consumers. As noted earlier, this is currently is not represented sufficiently. For example, investments in electricity recharging infrastructure can significantly increase the acceptance of electric vehicles and thus the behaviour of consumers can have important implications for the adoption of the technology. Strategic collaboration with groups in this area is necessary to fill the gap. The underlying model methodology lends itself to such an explicit representation of behavioural change and related policies.
  - On the demand-side, technology innovation and technology diffusion processes are well represented and offer a step forward compared to existing energy system models.
  - On the supply-side, better documentation of potentials and a more detailed representation of technology innovation and dynamics (particularly power generation) would help the model to address lock-in and path-dependency issues that are characteristic of energy systems.
2. Overall, there is significant demand-sector disaggregation, which should allow demand-side policies (e.g. relating to energy efficiency) to be examined in more detail than is frequently the case.
3. One value of being a whole energy system model is that POTEnCIA should be able to model the interactions between policies implemented in different sectors or with different scopes. However, given the lack of scenarios developed so far, it is not currently possible to see to what extent supply-demand interactions are adequately represented.
4. The capability of POTEnCIA to cope with different scenarios has not yet been proven, although this is an important element of the utility of the model for the policy-making process. Only one "test" scenario was available to the Panel – the "NoPol" scenario – and this has limited usefulness in terms of assessing the model as a tool for assessing decarbonisation strategies because it doesn't even include existing polices, such as the EU-ETS Directive. Before publication of the model, the Panel suggests running a small set of scenarios of different CO_2 emissions stringencies, showing the potential use of the model. These scenarios should include a set of contrasted technological settings in order for instance to test the ability of POTEnCIA to model high penetrations of renewable energy in a credible way.
5. The policy analysis needs are covered by the model through the development of a vision for the future energy systems in all Member States. The implementation of intra-EU grid connections and energy exchanges is in progress and should receive high priority.
6. Sectoral economic impacts are calculated by the model, but need better elaboration in the documentation. Macroeconomic impacts should be considered by linking with other models such as GEM-E3.

3. Adequacy and validity of the data used in the model (data sources and data decomposition)

1. The JRC-Integrated Database of the European Energy Sector (IDEES) is both a prerequisite and a valuable additional output from the modelling exercise that will most likely yield significant value-added to the policy-scenario modelling community in Europe and beyond. By standardising data according to Eurostat categories, and by including a large number of external primary data

sources, the IDEES database can become a reference for other energy-oriented quantitative works. The update from the year 2010 (currently used) to 2014 should be carried out as soon as possible, to overcome the inconvenience of having to use data from the last decade.

2. The effort to construct IDEES, a dedicated database adapted to the needs of the modelling process, is an extremely positive development to support the implementation, reliability and transparency of the model. All data in the IDEES database should be made available publicly and free of charge.
3. The data sources and empirical analyses that have been conducted to derive the parameterisation of the model currently remain opaque. The model documentation needs to be improved, with more examples of the empirical work used to derive the relationships and parameters (particularly of the logit/fuel choice model functions).
4. There is an incoherence in the modelling to the extent that it is suggested that nuclear fission is a competitive energy, which is contradictory to the real-life fact that not a single nuclear power plant in the world has ever been built under competitive market conditions. One possible explanation is that some important cost elements are omitted, such as insurance costs (for environmental risks), decommissioning, and long-term storage.

4. Robustness and validity of the scenario building approach/process (interaction with other modelling tools/involvement of stakeholders)

1. The scenario building approach has not been presented with sufficient detail.
2. As a first step, the focus of the scenarios should be on testing, illustrating and validating the dynamics and features of the model. This will be critical for gaining the confidence of all stakeholders.
3. The design of the policy scenarios is planned for the near future. For this, the soft coupling of POTEnCIA with a computable general equilibrium model (CGE) is a desirable step, which is feasible given the local JRC in-house model GEM-E3. The linking of POTEnCIA to other models, e.g. for international fuel prices, is also foreseen. These important steps are planned for the near future and should enable POTEnCIA to generate scenarios in 2017. The implementation of policy scenarios in the current model setting is relatively straightforward, it can be done by varying both the exogenous market acceptance factors (e.g. “more flexible natural gas plants”), the estimates of future technologies (e.g. “cheaper and earlier electromobility”), but also by adapting parameters such as elasticities of substitution. It is important that the “clients” of the scenarios are integrated into the scenario definition process at an early stage; this holds not only for the DGs (Clima, Energy, Move, JRC), but also for the Member States’ experts, whose involvement should be actively pursued.

5. Transparency of model and data

1. It will be necessary to develop a glossary in plain language for the definition of the different model variables and parameters.
2. The "evidence base" used to derive the parameters in the model needs to be clearly interpretable and easily verifiable by the model users.
3. The success of POTEnCIA, both in the academic and policy worlds, will depend, in part, on it being described clearly and in-depth, and being available in a transparent and accountable

manner. It is not clear why full open source access to the code is not envisaged, JRC being able to maintain its patronage over the model and the process, but potentially benefiting from a greater diffusion in the modelling world.

4. A clear strategy needs to be developed regarding model access (both use and development). This strategy should describe the process (clarify the main conditions and rules) for how third parties may use the model, and how further developments by external users could be incorporated into the main JRC model version. This could create shared ownership and facilitate POTEnCIA to become a “community model” within Europe, with JRC in the lead for deciding on critical developments. Shared ownership will be instrumental also for widespread acceptance and transparency of the model.
5. The high level of detail and the presentation of the complete set of results is not enough to ensure transparency: “too much information kills information”.
6. To help with the communication of scenario results, an effort is needed to define a format for model results that includes, not only the full details currently available, but also a structured intermediate level of hypotheses and results, with the definition of policy relevant indicators in compact dashboards.
7. A strategy for publishing model versions (perhaps different modules) in peer reviewed journals should be developed.

Annex 1: Modelling of the residential and services, industry and transport sectors

1. POTEnCIA energy demand simulation framework

As a hybrid partial equilibrium model, POTEnCIA provides a highly disaggregated description of the residential and services sectors as part of the energy demand module. The approach takes into account demand technologies, consumer behaviour and the impacts of different policies and measures.

Table 1 Types of representative economic agents per sector

Sector	Representative Economic Agent
Industry	Physical output indicator
Residential	Representative Household Representative appliance
Services	Serviced area (m^2) Representative unit
Agriculture	Equivalent physical output indicator
Transport	Mean of transport (e.g. car, train, plane, etc.)

The main features of the model confirm its ability to represent key drivers and constraints to changes in energy demand:

1. The investment in, and the operation of, energy consuming equipment, denoted by a “Representative economic agent” (agents are generally defined at the technology level rather than at the level of human or economic agents. Thus, the term of “Representative consumption unit (RCU)” would probably be less confusing and will be used hereafter).
2. The capital stock vintages, which are essential in order to differentiate the rate of use of the different vintages (with different cost and performance characteristics), provide an accurate description of energy demand.
3. Endogenous technology dynamics, with three categories of technologies for each RCU, defined as 1) ordinary, 2) advanced and 3) “state of the art”, plus 4) a “backstop” - standing for a fully optimised solution (again a change in terminology to 1) standard, 2) advanced, 3) “best available” plus 4) optimised, would probably be more immediately understandable).
4. The non-energy equipment parameters reflect differences in 1) the production structure of EU Member States (**PSP**, as computed from the IDEES database) 2) the efficiency of the infrastructures (**IEP**, a permanent feature such as building insulation), 3) the behavioural response (**BRP**, the temporary level of use of the energy equipment), 4) the structural response (**SRP**, reflecting the linking of activity levels in the different sectors).

An interesting feature is the way that the POTEnCIA model distinguishes different **sizes of equipment** and differentiates between the **realised level of use** of the equipment and their **desired level of use** that may represent a welfare target. This is essential for the representation of underutilized industrial capacity, e.g. resulting from an economic crisis or recession. It is also essential (but not sufficient, see below) for tackling the consequences of energy poverty (which may affect 11% of the EU population). The investment decisions are simulated through a nested decision-tree identifying: 1) the **cost** of each solution, 2) the **market acceptance factor** (that account for country specific biases in consumers’ preferences and deviations from optimality).

The framework also allows for the **premature replacement** of installed capacities, a feature which is not commonly found in simulation models. Premature replacement of current infrastructure is particularly important for the ability of the model to represent rapid system changes where, due to rapid changes in conditions, existing/dominant systems need to be replaced before the end of their life-times.

POTEnCIA Industry sector

POTEnCIA includes a detailed representation of the energy equipment of the industrial sector, broken down into a number of different sub-sectors and their alternative energy requirements. Non-process and process-related energy uses are represented separately from industrial non-energy uses, such as feedstocks. As is common in many detailed energy-system models, major energy intensive industries are represented explicitly in POTEnCIA, and are distinguished from non-energy intensive industrial demands. Industrial production in POTEnCIA is a function of (1) value added, (2) value added intensity, and (3) assumptions with regards to the production structure (PSP). All three parameters are, by default, exogenous (with the latter being constant over time), although the value added intensity can change endogenously within the model in response to the introduction of a policy. The PSP parameter can be also linked to economic and policy assumptions with feedbacks on value added. Whether the (non-linear) formulation is consistent with empirical observations is not discussed in the model documentation.

POTEnCIA Residential sector

The energy profile of a Representative consumption unit (in our terminology) for the residential sector encompasses: the building shell features, the four thermal uses (space and water heating, cooking and cooling described for investment decisions in 43 “clusters”, i.e. combinations of equipment and energy carrier), five specific electricity uses (lighting, white appliances, TV, ICT, other). In the specific electricity demand simulation, the number of occupied households is multiplied by a penetration rate for each appliance, while heating needs are simulated by taking into account the size of the equipment, desired level of operation and realised hours of operation. Investment decisions are taken at the level of a cluster of end-uses. In addition to modelling reactions to prices and costs changes, the impacts of policies and measures are introduced through changes in the IEP (building shell) and BRP parameters with actions or behaviours that can be reversed.

POTEnCIA Services sector

In the service sector, thermal uses are considered independently and a distinction is made between the building cells (the number and surface of which depend on the value added of the sector) and the number of users that request each service (fraction of the total population).

POTEnCIA Transport sector

In common with the other demand sectors, POTEnCIA includes a detailed technological representation of the transport sector. It comprises road, rail, aviation and water-based transport and, for each transport mode, relevant combinations of different engine architectures and fuel options are represented explicitly in the model. Furthermore, bunkers are included in the model. Representative consumption units in the transport sector are the technologies operating in different modes. POTEnCIA considers differences in vehicle ownership and occupancy rates across EU Member States. For other mobility-relevant parameters, however, POTEnCIA is quite aggregated. It does not account for heterogeneity of consumers, and differences between urban and rural transport are only considered in a rudimentary way. Behavioural response is particularly critical for the transportation sector, and is represented in an aggregated way through the so-called production structure parameter (PSP). PSP is a function of the change in price of one mode compared to the average price across all modes.

2. Strengths of POTEnCIA's demand-side modelling approach and the treatment of endogenous technology

Technological detail (all sectors)

POTEnCIA's strength lies in the detailed technological representation of the demand sectors, which thanks to the IDEES database, are calibrated to the specific circumstances of different EU Member States.

Capital vintages (all sector)

The strength of POTEnCIA lies in the combination of a high level of disaggregation of the Representative Consumption Units and corresponding energy needs and the careful simulation of the way different capital vintages are used and renewed. A specific asset is the ability of POTEnCIA to model premature replacement of capacity.

Structural parameters (residential sector)

The way POTEnCIA takes account of a chain of structural parameters in the decision-tree allows a description of differences across countries or changes in consumers' behaviours in the residential sector (while behaviour in the transport sector is less well represented so far, see below). This will probably prove to be a powerful tool for accurately describing changes in residential energy demand and for the simulation of public policies based on different types of instruments and measures.

Dedicated IDEES database (all sectors)

The development of IDEES, a dedicated database, whose structure is designed to provide the data that are used in the model is a very strong point. But the IDEES database also provides, through appropriate computations, estimates for the parameters used in the behavioural equations, while taking into account sectoral or national differences. This may prove to be a key element for developing a dialogue between POTEnCIA modellers and users in different Member States, provided that the underlying economic rationale and the values identified are made clearly understandable to users.

Endogenous technology dynamics

The incorporation of endogenous technological change for energy demand technologies is a major asset of the model. A distinction is made between three levels of technology performance, plus an optimised solution that allows a truly endogenous treatment of technology progress for the "many small" energy demand technologies. This represents a truly original feature of the model.

The incremental endogenous technology improvement corresponds to a catch-up process towards the efficiency frontier, with the speed of the catch-up proportional to the distance to the frontier. This is consistent with econometric analyses, performed at a more macro-level, by Acemoglu *et al*.[1]

Last but not least, the representation of different technology vintages allows the introduction of exogenous efficiency policy standards or the simulation of technology breakthroughs, with direct and indirect effects on the costs and performances of the different vintages.

3. Weaknesses, challenges to be overcome and recommendations

i. As already mentioned above, the terminology used in order to describe the modelling processes, variables and parameters (e.g. Representative economic agent, Backstop technology…) are at time idiosyncratic and do not help in the understanding of the mechanisms. This may be solved either by a partial revision of this terminology or by the careful development of a glossary, with examples, that may help the non-modeller to understand the functioning of the model and the economic significance of the parameters.

ii. This is all the more important as the POTEnCIA model is designed to overcome the “black box” syndrome that affects many large applied energy models. Overcoming the corresponding barriers to dialogue between the different DGs of the EC and between the EC and Member States’ experts is probably the first condition for the success of the POTEnCIA project. If POTEnCIA was to become a common tool for facilitating dialogue about energy and climate policy design and implementation, this would be a giant step forward.

iii. The model documentation rarely includes any empirical validation of key parameters, such as for example the PSPs. For each demand sector the mathematical relationships of the PSPs, as well as the empirical calculations for deriving the parameters, need to be transparent.

iv. Industrial sector: POTEnCIA shares with other energy models the weakness of exogenously specifying industrial value added, as well as assuming no structural change (in its default mode). The possibility of representing structural change is discussed, but not made transparent.

v. Residential and Services sectors:

    a. First, while the introduction of different levels of energy performance in the end use consumption is clearly an advance in the modelling framework, one key issue in the energy transition process – the thermal retrofitting of buildings – is not explicitly addressed, since the model lacks a building stock module. In the existing modelling framework, such retrofitting can be introduced through changes in the Infrastructure Efficiency Parameter; but the details of this introduction and of the complexity of the different issues to be dealt with (identification of different building types, decision functions in single ownership or condominium, specific financing problems, technical accompaniment programmes, rebound effects…) are not clearly addressed. As these issues are of utmost importance, they should be a focus of future model development.

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[1] Acemoglu, D., Aghion, P. and Zilibotti, F. (2006) Distance to frontier, selection, and economic growth. *Journal of the European Economic Association*, 4(1):37–74.

   b. Associated with this, it appears that issues of lifestyles related to incomes, the gap between desired and effective comfort level (with significant consequences for the rebound effect) and of decision making under conditions of energy poverty cannot be adequately addressed in a framework with only one representative agent. Notwithstanding the data problems that may arise with identifying consumption units by income category in different countries, it seems that dividing the representative agent into a limited number of categories is a condition for a significant improvement of the residential sector in the model.

vi. Transport sector: Representation of behavioural barriers and opportunities is critical for the modelling of transformative change in the transportation sector. In this context, POTEnCIA focuses on technology resolution rather than the representation of social and consumer heterogeneity. The latter is, however, a pre-requisite for an appropriate representation of behavioural changes in the transport sector. It is recommended to extend the model to better represent urban vs rural consumers, as well as the dependency of their preferences/choices conditional on other salient energy policies (such as infrastructure investments). Currently, POTEnCIA relies on exogenous assumptions about behaviour. Through a better representation of the determinants of behaviour, POTEnCIA should hopefully, in the future, be able to model policies for behavioural changes.

Annex 2: Modelling of the power sector

1. Model setup and descriptive analysis

Significant efforts have been made in POTEnCIA to allow a more disaggregated representation of the power sector, and the approach chosen, i.e. the exogenous identification of "market acceptance factors", succeeds in establishing the 2010 status quo and backcasting for earlier years. Given the strong limitations of the time resolution (only seven time slices) and the conservative approach that more or less maintains the structure of the 2010 mix based on conventional energy sources, the current implementation of the power sector is not capable of anticipating the kind of disruptive changes that are already occurring, i.e. the future operation of a largely renewables-based system, where ramping capabilities and the use of various storage technologies (electrochemical, power-to-heat, etc.) play a central role. This dilemma could be resolved by sequentially running a longer-term optimization model for power sector investments (at the European and the MS level) and then updating the "market acceptance factors" in POTEnCIA through backward induction.

Instead of "economic optimization", a flexible behavioural approach was chosen for the entire POTEnCIA model family, based on simulation. The determination of – exogenously defined – "market acceptance factors" allows a very flexible allocation of power generation technologies to aggregated load patterns. In fact, by applying country-specific market acceptance factors, the model can be calibrated such that the specifics of each Member State are taken into account. Thus, POTEnCIA succeeds well in establishing the 2010 status quo, and the backcasting for earlier years. However, as discussed later, this strength may correspond to a weakness in assessing future power systems when disruptive change is probable.

To fit with the rest of the POTEnCIA model family, the power sector module introduces the notion of a "representative day" for the demand (called "load") which forms the basis of the subsequent demand-supply balancing. Through a clustering approach the extremes (such as "top day", "valley day", etc.) are synthesized into a representative day, representing the necessary characteristics of the load profile. To this, an endogenously calculated reserve margin is added, that is designed to address system security issues. The load of the "representative day" is then grouped in seven "load slices", to which both operating and investment decisions are applied.

Intermittent (variable) renewable energy sources (VRES) are considered in this context as an "add-on", and they are integrated in a way to "perturb" the conventional fossil-fuel and nuclear technologies as little as possible. The allocation of VRES to load profiles is not made according to their most likely appearance (e.g. sun in hours 8 -18 of a day), but rather is allocated such as to minimize the total system operating costs. Since VRES are supposedly not able to contribute to baseload, their share is penalized by an availability factor, leading to a focus of the model on conventional sources.

Mandatory production requirements are also introduced, thus reducing the flexibility of the electricity system significantly. In particular, electricity generated from cogeneration power plants constitute a significant so-called "must-run" contribution, since "for cogeneration power plants it is considered that they are primarily dispatched in satisfying a distributed steam demand curve" ("POTEnCIA model description version 0.9", p. 66, footnote 41); this leads to minimum electricity production requirements, the so-called "must-run". Other mandatory production includes quotas set by policies, e.g. generation from biomass or variable renewables.

With respect to capacity planning and investment, the model is able to distinguish between three different behavioural assumptions, i.e. 1) individual dedicated producers that have no concern for system costs; 2) multiple market agents with heterogeneous behaviour; and 3) a central decision planner. The traditional perfect-foresight-optimization with perfect information is replaced by foresight with imperfect information and a strong role for expectations, e.g. concerning the likelihood of certain policies, such as ETS, efficiency, renewables, etc. In identifying investment needs, POTEnCIA uses the same approach as for operation of the system, catering to conventional fossil-fuel and nuclear energies, through the "market acceptance factor".

2. Strong points

Given the strong heterogeneity of Member States' electricity mix, the approach chosen provides a high degree of flexibility to backtrack the specific structures, using the multinomial logit model and the "management approach". The approach is particularly suited for a static environment, where the dominant shares of different conventional capacities are taken as given. The description of the approach is clear even though there is a lumping of variables, combining "hard" technical variables (such as efficiency values, ETS-factors, etc.), and "soft" policy parameters with unclear origin (e.g. e_{pol}, i.e. the "elasticity for the reaction of the market acceptance factor to policy-induced costs").

The "representative day" notion is a significant step in synthesizing yearly and daily load patterns, and the clustering to seven load types assures reasonable runtimes of the model. The possibility to choose between three types of investment decision-making is particularly instructive, because it allows the identification of specific investment patterns. Some specification of the notion of "a central decision planner" is required, though: traditionally this notion refers to a welfare-maximizing central planner ("good dictator"), whereas here the actor seems to be a "large utility", which could even be tempted to abuse its market power. The introduction of the second layer, "multiple market agents", allows a very high degree of differentiation, e.g. by attitude, age, sex, etc. However, the specification of these agents needs to be done with care and a high degree of transparency in order not to overload the user with complex information.

At present, the representation of energy networks in POTEnCIA is still underdeveloped, but efforts are being made to fill this gap by the end of 2016, in particular through "one-country-one-node" networks for natural gas pipelines and electricity transmission lines (there is no mention of CO_2-pipeline networks, although some power plants with carbon capture, transport, and storage appear in the 2030s). Given the complexity of calculating more granular infrastructures, in particular for electricity, this modest approach seems to fit well in the list of "medium-term"-priorities, and thus expectations that the future use of POTEnCIA can deliver line-by-line network results (quantitative, or monetary) should be moderated.

3. Identified weaknesses

3.1 Model setting cements current structure of conventional generation

If maintained as such, the strength of the model, i.e. the identification of the electricity mix "by hand" through the choice of behavioural and market acceptance factors, will turn out to be a weakness of POTEnCIA, as it is not capable of dealing with disruptive change in the electricity sector, e.g. the breakthrough of solar photovoltaics as a baseload technology. In combination with the low capability of the model to reflect the dynamics of future electricity systems, POTEnCIA has a tendency to fix the current, relatively inflexible energy mix which largely relies on conventional, fossil-fuels and nuclear power. Even if it is technically possible, the current model set up does not allow for the kind of disruptive change that is already occurring i.e. the emergence of a more decentralized, largely renewables-based system including storage, in the context of a high degree of decarbonisation (80-95% by 2050).

3.2 Restrictive modelling of representative day in conjunction with backward-looking "market acceptance factors" (self-fulfilling prophecies)

The chosen approach does not correspond to the evolving state-of-the-art of power sector modelling, mainly with respect to the choice of baseload technologies, which is, by definition, composed almost exclusively of conventional plants (Section 3.3.3 "Priority dispatch …", p. 19, as well as Section 5, in particular Section 5.2.3 "Simulation of power plant unit operation", pp. 63 sq.). The inflexibility of the "representative day" approach was deliberately chosen to fit the relevant time dimension of the other sectors; yet it corresponds to a rather static power system analysis that relies almost fully upon conventional generation. In the new context of a largely decarbonized electricity system, the **flexibility** of the system becomes the main driver, including ramping, storage, etc. In order to capture these effects, a more detailed dispatch and investment model should be run in parallel (see recommendations below). It would be useful to complement the chosen approach ("representative day") by runs of a power market and investment model of much higher granularity of time, including more recent technological options; this "co-model" could produce forward looking electricity mixes, both for the European Union 28 and for each Member State, which could then be used to adapt the individual "market acceptance factors"

Some key assumptions further limit the flexibility of the model to deal with technical change: one of them is the fixed steam output of cogeneration plants, which introduces a high share of conventional "must-run" capacities. Today, there are different alternative options to generate steam, e.g. decentralised boilers, or power-to-heat-storage (e.g. from abundant renewables). Another issue is the way the rather general boundary conditions of how the "sufficient capacity" requirement are determined; quantitative results from the NoPol-scenario suggest an average reserve margin of 2 (net installed capacity / peak), which seems to be quite high (and further induces investment into conventional technologies). But this parameter could easily be adjusted.

3.3 Insufficient representation of currently technologies

The interaction of renewables with associated storage technologies is not mentioned, which increases investment in conventional technologies. Yet, the use of the "representative" day notion leads to an under representation of the variation of renewable infeed fluctuation, both on a spatial as well as temporal basis. This also affects the use of storage technologies that might be incorporated in the model framework. In electricity systems affected by intermittent renewable sources, storage technologies play an increasing role to mitigate the intermittency in the presence of severe CO_2 constraints. Technological progress has been considerable over the last 5 years, mainly with respect to batteries, such as lead, lithium-ion, etc. and a further massive reduction of costs is expected for the next decade, e.g. in the wake of the "Gigafactory" of lithium-ion batteries opening up in the U.S. in 2016. It is surprising, therefore, that electricity (and heat) storage do not seem to play a significant role in the POTEnCIA model: while some hydro-power storage is considered, as well as fuel-cells, none of the alternative storage technologies are mentioned. This may have to do with the use of the IDEES database of 2010.

It will be important that the data used by the POTENCIA model is updated regularly to reflect the latest developments, particular for those technologies such as solar photovoltaics that are seeing rapid cost reductions. At the moment some of the data projections are too pessimistic.

3.4 Conflicting views on the costs and competitiveness of nuclear power

The nuclear cost estimates used in POTEnCIA seem to ignore system costs, in particular decommissioning and waste storage: The capital costs of nuclear power plants (NPPs) are purely private upstream costs, and ignore "social" economic costs, such as damage risk. It seems that they also ignore the full costs of the fuel cycle, in particular the back-end costs of decommissioning and long-term waste storage.[2] The estimated capital costs assume a significant increase of deployment, in the period 2030-2050 (+ 22 GW). Given the costs structure of nuclear power, this may be the results of politically determined investments, for which a break-down by country would be useful (both Nuclear III and Nuclear IV generations). The drop of average capital costs of Nuclear IV generation would suggest significant investments into this technology in the 2020s, which may or may not be plausible from today's perspective.

In general, the treatment of nuclear power is very difficult in any technical-economic model, since investments into nuclear power plants (NPPs) have never been carried out based on economic considerations in a competitive market environment. As Davis (2012) and Lévêque (2014)[3] report based on a very detailed account of previous literature, the nuclear industry has so far not been able to prove a purely economic rationale for private investments, and the situation has deteriorated with low natural gas prices (mainly in the U.S.), and decreasing costs of renewables (worldwide). On the other hand, some EU Member States are still planning investments into NPPs. An alternative approach, that would seem to be more transparent, would involve the new investments into NPPs being set exogenously by the modelling team, based on announcements of the Member States (that should be checked for consistency); in a second step, the ensuing dispatch and price results should then be calculated.

4. Recommendations

In order to adapt POTEnCIA to the challenges of a very dynamic power energy mix of the future, the following recommendations should be considered:

- Clarify the description of the power sector, in particular Section 5 of the "POTEnCIA model description", mainly with respect to the chosen variables and the distinction between "technical" and "behavioural" parameters;
- Complement the chosen approach ("representative day") by runs of a power market and investment model of much higher granularity of time, including more recent technological options. This "co-model" could produce forward looking electricity mixes, both for the European Union 28 and for each Member State, which could then be used to adapt the individual "market acceptance factors";
- Introduce a coherent set of state-of-the-art technologies, including appropriate, recent cost figures, in particular for storage technologies, and solar PV;
- Introduce a more consistent treatment of nuclear power, e.g. by adopting exogenously set nominations by Member States, and then adapting the dispatch accordingly;

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[2] These turn out to be very significant, e.g. € 1,500/kW for decommissioning only (case of Wuergassen, Germany).

[3] Davis, L.W., 2012. Prospects for Nuclear Power. Journal of Economic Perspectives 26, 49–66; and Lévêque, F., 2014. The Economics and Uncertainties of Nuclear Power. Cambridge University Press, Cambridge, United Kingdom.

- Provide one alternative base-run with parameters chosen deliberately to be very different from the existing base-case, such as to identify drivers and possible ranges of results.

Annex 3 Biographies of the Review Panel

Professor Leen Hordijk *Professor Environmental Systems Analysis, Wageningen University (emeritus) and Principal Adviser to the Director-General (retired), Joint Research Centre of the European Commission (JRC).*

Professor Dr. Leen Hordijk started at the JRC as the Director of the Institute for Environment and Sustainability in Ispra (Italy) in May 2008 and was appointed Principal Adviser to the Director-General of the JRC and Head of the Task Force on Modelling in September 2011. Before joining the European Commission, Professor Hordijk was from 2002-2008 the Director-General of the International Institute for Applied Systems Analysis (IIASA), in Laxenburg, Austria. Prior to joining IIASA, he was Director of the Wageningen Institute for Environment and Climate Research in the Netherlands and from 1991 until September 2011 professor in Environmental Systems Analysis at Wageningen University. He was also Chairman of the Social Science Division of the Netherlands Organisation for Scientific Research (NWO). Leen Hordijk received his Ph.D. in economics from Vrije Universiteit, Amsterdam. Beginning in 1984, he pioneered the development of methods for linking environmental science and economics for integrated assessments of air pollution problems in Europe. The models he and his colleagues developed, mainly at IIASA in Austria, were widely used. His approaches are recognised as among the most effective ever developed for linking science and policy in international environmental affairs. He has also been engaged in regular short term stays for teaching in universities in the USA, China and Vietnam.

Professor Patrick Criqui *Senior researcher at CNRS in charge of the Economics of Sustainable Development and Energy research group (GAEL-edden, UGA-CNRS, Grenoble).*

Patrick Criqui's research initially explored the economics of solar energy and the modelling of international energy markets. He then developed a world long term energy model, POLES, which is currently used by the European Commission and by different administrations and companies in Europe to analyse the economics of climate policies. He has been a lead author in IPCC's Working Group 3 (collective Nobel Peace Prize in 2007). Member of the Economic Council for Sustainable Development by the French Minister of Ecology since 2008, he has been expert on Scenarios for the National Debate on Energy Transition (2013) and for the National R&D Strategy, on energy issues (2014). Since 2015, he is member of the Expert Committee for the Energy Transition. Also member of the scientific council of the Institut Français du Pétrole and of the Fondation Nicolas Hulot, he has taught and teaches in different universities in France and abroad.

Professor Keywan Riahi *Director, Energy (ENE) Program, International Institute for Applied Systems Analysis*

Keywan Riahi is Program Director of the Energy Program at the International Institute of Applied Systems Analysis (IIASA, Austria). In addition he holds a part-time position as Visiting Professor in the field of energy systems analysis at the Graz University of Technology, Austria. Professor Riahi is currently Project Coordinator and member of the Coordination Board of the EU Horizon 2020 project on 'Linking Climate and Development Policies-Leveraging International Networks and Knowledge Sharing'/CD-LINKS (2015-2019). Professor Riahi is also a member of the Scientific Steering Committee of the Integrated Assessment Modeling Consortium (IAMC) and a number of other international and European scenario activities. His work within international modelling comparison projects, such as the Stanford-based Energy Modeling Forum (EMF), focuses on the spatial and temporal characteristics of technology diffusion and the path-dependent development of the energy system under alternative policy configurations. Since 1998, he has served as a Lead Author and Review Editor to various international Assessments, such as the Global Energy Assessment (GEA), and Reports of the Intergovernmental Panel on Climate Change (IPCC), including the IPCC's Third and Fourth Assessment Reports, the IPCC's Special Report on Emissions Scenarios (SRES), the Special Report on CO2 Capture and Storage (SRCCS), and the Special Report on Renewable Energy (SRREN). Recently he has also been appointed a Lead Author of the IPCC 5th Assessment Report. Professor Riahi's main research interests are the long-term patterns of technological change and economic development and, in particular, the evolution of the energy system. His present research focuses on energy-related sources of global change, and on future development and response strategies for mitigating adverse environmental impacts, such as global warming and acidification.

Professor Peter Taylor *Professor of Sustainable Energy Systems, University of Leeds*

Prof Peter Taylor holds a Chair in Sustainable Energy Systems at the University of Leeds and is also a member of the UK Energy Research Centre and UK Centre for Climate Change Economics and Policy. His research and teaching are at the energy technology / policy interface and he has particular interests in long-term, low-carbon energy technology transitions and the innovation and other policies needed to achieve them. From 2007 to 2011, Peter Taylor was Head of the Energy Technology Policy Division at the International Energy Agency in Paris, responsible for high profile publications such as the *Energy Technology Perspectives* and *Energy Technology Roadmap* series. In a previous consultancy career, he was Technical Director of a major UK energy and environmental practice and worked extensively for the UK Government and European institutions on energy technology policy issues.

Professor Christian von Hirschhausen *Professor of Economics at the Workgroup for Economic and Infrastructure Policy, Berlin Institute of Technology*

Christian von Hirschhausen is Professor of Economics at the Workgroup for Economic and Infrastructure Policy (WIP) at Berlin Institute of Technology (TU Berlin), and is also Research Director at DIW Berlin (German Institute for Economic Research). PhD in Industrial Economics from the Ecole Nationale Supérieure des Mines de Paris, previously Chair of Energy Economics at TU Dresden. Prof. von Hirschhausen focuses on the regulation and financing of infrastructure sectors, mainly energy, and is a regular advisor to industry and policymakers, amongst them the World Bank, the European Commission, European Investment Bank, and several German Ministries. Von Hirschhausen also focusses on energy technologies, and the technology – economy – policy interface.

3 JRC Reply to the Peer Review Panel

Dear Professor Hordijk,

Dear Leen,

Dear members of the POTEnCIA peer-review panel,

I would like to thank you all for your efforts in undertaking this exercise.

I would also like to use this opportunity to inform you about a number of POTEnCIA model developments that took place since the peer review meeting on March, 1 and 2, 2016 (that as mentioned at that time they were ongoing).

- Electricity interconnections between Member States have been implemented and are fully operational; this model feature is currently being validated with DGs ENER and CLIMA.
- Electricity storage options have been further enhanced, going beyond those initially captured by POTEnCIA.
- The JRC-IDEES database has been fully updated and now covers the period 2010-2015. It will be made publicly available in May 2017.

In parallel, the continuous POTEnCIA model validation process has been further intensified inside the European Commission between the JRC and the relevant policy DGs ENER, CLIMA and MOVE. This interactive process focuses on the analysis of 'stylized policy scenarios' illustrating the model's response to changing policy assumptions. Until July 2016 the validation process took place by means of analysing different scenarios at the level of the EU as one entity, whereas from July onwards the analysis takes place by simultaneously addressing the evolution of the EU energy system on a Member State by Member State basis. The scenarios examined address the role of various policy options related to energy efficiency, technologies deployment and the decarbonisation of the energy system or combinations of them, as well as, the role of electricity network interconnections. Within this process, POTEnCIA has demonstrated to be rather reactive to policy assumptions in a consistent and coherent manner.

We will now continue with the communication process envisaged for making the tool and the related documents and databases public to the scientific community and Member States. To complement the Panel's report we plan to publish the annexed document with additional information and clarifications as well as progress on the tool development since the peer review meeting.

Yours sincerely, and Happy King's Day

Piotr

26.04.2017

Dr. habil. Piotr Szymański

Director JRC C

ADDITIONAL CLARIFICATIONS AND INFORMATION ON IMPLEMENTATION OF SUGGESTIONS OF THE PEER-REVIEW REPORT

In the following, numbered points and pages within the quotes refer to the final Report by the panel, whereas pages quoted in the bulleted paragraphs, as well as literal quotations therein refer to the POTEnCIA description document[1]

Point 2.4:

Peer review report: "The treatment of the power sector is more aggregated than the demand sectors, with only seven time slices, and uses the concept of "market acceptance factors" to determine the mix of electricity generating technologies. The Panel is concerned that this "conservative" approach may limit the ability of POTEnCIA to model the kind of disruptive changes that are already occurring."

- The model simultaneously addresses both the chronological load pattern (24 hours) and the different load regimes (7, ranging from the base load to the peak load). Hence, instead of only seven time slices, the power generation in POTEnCIA considers 7*24 time/load combinations (pp50-52).
- Market acceptance factors do not primarily determine the mix of electricity generating technologies. Following the logic underlying the discrete choice theory, the attractiveness of a technology compared to the competing technologies is determined primarily by its relative cost, and then also by a parameter accounting for non-economic factors (here called the market acceptance factor). Rather than leaving this parameter to the arbitrariness of the model user, POTEnCIA introduces an endogenous adjustment mechanism for it, thus rendering the model less prone to ad-hoc manipulations and at the same time more reactive to changing policy frameworks in a consistent transparent manner (pp62-63).
- The stylized scenarios assessed during the course of the year 2016 clearly demonstrate that POTEnCIA is perfectly able to accurately model also extreme scenarios. Such scenarios have been analysed in detail between the JRC, DG ENER, DG CLIMA and DG MOVE.

Point 3.1.6

Peer review report: "The approach chosen for many of the sectors of defining "market acceptance factors" is generally successful in explaining the observed energy shares (through multinomial logit distributions). However, there is a risk that if the market acceptance factors are kept constant over time then the model will simply forecast past energy trends into the future. This could be a particular danger in sectors where cases of disruptive innovation are likely (e.g. the power sector). For the demand sectors, the model structure allows these market acceptance factors to be modified endogenously in future years in response to changes in economic conditions and the introduction of policies. For the power sector, any changes need to be exogenously defined. For all sectors, particular attention should be given to making sure that the development of the market acceptance factors adequately reflects the impacts of all drivers which can affect technology acceptance. Fully endogenising this feature will require some future model enhancements e.g. to link the acceptance of electric vehicles to developments in the re-charging infrastructure."

- The market acceptance factor is only one of the elements affecting the investment decision making (see also comment on point 2.4, above). They are fully endogenised in POTEnCIA as to capture possible policy related effects both for the demand side and for power generation (pp29, 62). But even if the market acceptance factors were kept constant the market shares of the alternative options would change over time and across the different policy scenarios as a result of changes within the discrete choice model mechanisms.
- One of the modelling principles adopted when designing POTEnCIA was to obtain a modelling tool able to assess scenarios with a minimum of exogenous interventions. A scenario can be defined by modifying only the one relevant parameter (e.g. the CO_2 price). This has been made possible through the introduction of numerous mechanisms that

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[1] Mantzos L. et al (2016): POTEnCIA model description version 0.9; JRC100638

endogenously capture a wide range of possible economic, structural, technology related and behavioural responses (pp10, 78-79).

Point 3.1.7

Peer review report: "There is a difference between the quite detailed level at which the demand side in various sectors is considered, and the relatively aggregated approach used to address the power sector (which has only seven load slices for one entire year). Given the limitations of the time resolution and the conservative approach (based on "market acceptance factors") that more or less maintains the structure of the 2010 mix based on conventional energy sources, the current implementation of the power sector is not capable of anticipating the kind of disruptive changes that are already occurring e.g. the future working of a largely renewables-based system, where ramping capabilities and the use of various storage technologies (electrochemical, power-to- heat, etc.) play a central role. This dilemma could be resolved by sequentially running a longer- term optimisation model for power sector investments (at the European and the Member State level) and then updating the "market acceptance factors" in POTEnCIA through backward induction."

- Concerning the market acceptance factor, the time resolution and the degree of reactiveness of POTEnCIA please see clarifications on point 2.4.
- POTEnCIA explicitly captures ramping capabilities; it is able to quantify – specific for each technology type and size - the additional energy requirements, CO_2 emissions and costs related to the operation of a power plant in cycling mode (pp57-62).
- Above mentioned features remove the risk of maintaining the 2010 mix.

Point 3.2.1

Peer review report: "In the transport sector, a major driver for policies and their effectiveness is the development of associated infrastructures with their impacts on the behaviour of consumers. As noted earlier, this is currently is not represented sufficiently. For example, investments in electricity recharging infrastructure can significantly increase the acceptance of electric vehicles and thus the behaviour of consumers can have important implications for the adoption of the technology. Strategic collaboration with groups in this area is necessary to fill the gap. The underlying model methodology lends itself to such an explicit representation of behavioural change and related policies."

- Infrastructure costs are explicitly accounted for at the level of technology options (p30). As stated in the POTEnCIA description, "such costs reflect both nominal costs, i.e. those of setting up a specific infrastructure, as well as costs related to its level of maturity. The infrastructure costs are represented through a cost increase factor, $inff$, which in turn links to fixed cost of the technology option…".

Point 3.2.4

Peer review report: "The capability of POTEnCIA to cope with different scenarios has not yet been proven, although this is an important element of the utility of the model for the policy-making process. Only one "test" scenario was available to the Panel – the "NoPol" scenario – and this has limited usefulness in terms of assessing the model as a tool for assessing decarbonisation strategies because it doesn't even include existing polices, such as the EU-ETS Directive. Before publication of the model, the Panel suggests running a small set of scenarios of different CO2 emissions stringencies, showing the potential use of the model. These scenarios should include a set of contrasted technological settings in order for instance to test the ability of POTEnCIA to model high penetrations of renewable energy in a credible way."

- The scope of the peer-review exercise as agreed between the review panel and the JRC comprised the validity of the methodological approach; the model capacity to adequately address European Commission policy analysis needs; the adequacy and validity of the data; the scenario building process; and the transparency of model and data. It did not include an assessment of scenarios.
- Following the reviewers suggestion, a comprehensive analysis of 'stylized policy scenarios' has been carried out in cooperation with relevant policy DGs. No problem in addressing even extreme policy scenarios with POTEnCIA was found. In addition, this could be achieved by only modifying the related policy parameter, as foreseen in the design specifications. For example in the case of a stringent decarbonisation scenario,

implementing a reduction of energy related CO2 emissions in the EU by 85% from 1990 levels by 2050, only required a modification in the exogenously prescribed carbon price. At the same time in this scenario the share of renewable energies in the power sector reaches above 80% in 2050 while maintaining system stability. This capacity of the modelling tool is of high importance as it limits the arbitrariness of exogenous interventions. This has been made possible through the introduction of numerous mechanisms that endogenously capture a wide range of possible economic, structural, technology related and behavioural responses.

Point 3.4.3

Peer review report: "The design of the policy scenarios is planned for the near future. For this, the soft coupling of POTEnCIA with a computable general equilibrium model (CGE) is a desirable step, which is feasible given the local JRC in-house model GEM-E3. The linking of POTEnCIA to other models, e.g. for international fuel prices, is also foreseen. These important steps are planned for the near future and should enable POTEnCIA to generate scenarios in 2017. The implementation of policy scenarios in the current model setting is relatively straightforward, it can be done by varying "both the exogenous market acceptance factors (e.g. "more flexible natural gas plants"), the estimates of future technologies (e.g. "cheaper and earlier electromobility"), but also by adapting parameters such as elasticities of substitution. …

- Scenario assessments in POTEnCIA are undertaken in the default setting through changes in the main policy parameters only. Any possible responses are captured endogenously in the model through a number of mechanisms, reducing the arbitrariness of exogenous interventions (see above).
- "Through the endogenous adaptation of the market acceptance factor, the model captures changes in the consumer's behaviour that are induced by changing preferences, shifts in economic conditions and the introduction of policies."(p 29)
- Technology dynamics on the demand side such as transport are fully endogenous, not only allowing a differentiation of technology characteristics between different countries, but it also "establishes a link between technology dynamics and policies". (pp14-15).
- "POTEnCIA introduces the possibility of a policy driven (endogenously derived) change in the elasticity of substitution of the market sharing function" in order to reflect that the "choice made by the representative agent would become more economically optimal" (i.e. reducing the consumer economic myopia) under the introduction of a strict policy framework (pp 11, 62).

Annex 2 – point 1

Peer review report: "Significant efforts have been made in POTEnCIA to allow a more disaggregated representation of the power sector, and the approach chosen, i.e. the exogenous identification of "market acceptance factors", succeeds in establishing the 2010 status quo and backcasting for earlier years. Given the strong limitations of the time resolution (only seven time slices) and the conservative approach that more or less maintains the structure of the 2010 mix based on conventional energy sources, the current implementation of the power sector is not capable of anticipating the kind of disruptive changes that are already occurring, i.e. the future operation of a largely renewables-based system, where ramping capabilities and the use of various storage technologies (electrochemical, power-to- heat, etc.) play a central role. This dilemma could be resolved by sequentially running a longer-term optimization model for power sector investments (at the European and the MS level) and then updating the "market acceptance factors" in POTEnCIA through backward induction."

- See comments above under points from 2.4 to 3.1.6
- The market acceptance factors contain a endogenously calculated scenario-specific element (p62)
- Time resolution is 24 hours; in addition seven load regimes are identified (pp50-53)
- The model set-up captures the multifaceted responses of consumers and investors to the introduction of policies, and does not maintain the structure of the 2010 mix.
- Ramping capabilities are explicitly addressed in POTEnCIA (pp57-62)

Peer review report: "Instead of "economic optimization", a flexible behavioural approach was chosen for the entire POTEnCIA model family, based on simulation. The determination of – exogenously defined – "market acceptance factors" allows a very flexible allocation of power generation technologies to aggregated load patterns. In fact, by applying country-specific market acceptance factors, the model can be calibrated such that the specifics of each Member State are taken into account. Thus, POTEnCIA succeeds well in establishing the 2010 status quo, and the backcasting for earlier years. However, as discussed later, this strength may correspond to a weakness in assessing future power systems when disruptive change is probable."

- Here are some clarifications:
    - "For the power generation sector POTEnCIA follows a <u>non-linear, price-lagged, optimisation approach</u>, simultaneously addressing capacity planning and power plants dispatching under" various constraints. (p18). "The operation of the power plant fleet is simulated as to meet the electricity demand at the minimum system operating cost" under a number of constraints." (p57)
    - A "multinomial logit formulation is applied as to reflect portfolio management constraints." (p56). "The adoption of such an approach is justified by the fact that, as explained earlier, in POTEnCIA a unit commitment approach is mimicked." "However, as it is not possible to address individual units (…), the dispatching process is narrowed down to some 270 representative unit types. For each of the latter a number of identical units can be considered (…). The properties of each representative unit type represent the average characteristics of the numerous similar (by means of equipment characterisation) units installed. The underlying real units may nevertheless have minor or larger deviations in their operating costs reflecting different technological characteristics that are strongly linked to their year of commissioning. This variety of units means that in real life their dispatching in the different load regimes would most likely be quite fragmented." "This fragmentation observed in real life conditions is what is captured through the use of the desired market shares when simulating the operation of power plant units." (p 65)

Peer review report: "Intermittent (variable) renewable energy sources (VRES) are considered in this context as an "add- on", and they are integrated in a way to "perturb" the conventional fossil-fuel and nuclear technologies as little as possible. The allocation of VRES to load profiles is not made according to their most likely appearance (e.g. sun in hours 8 -18 of a day), but rather is allocated such as to minimize the total system operating costs. Since VRES are supposedly not able to contribute to baseload, their share is penalized by an availability factor, leading to a focus of the model on conventional sources."

- Section 5.1.3: "In POTEnCIA the information about the potential contribution of intermittent renewable energies within each load regime is retained when moving from the chronological load curve to the discretised load regimes." "Firstly, given the chronological load duration curve of the representative day that needs to be satisfied, the potential contribution of intermittent renewable energies within each time segment (hour) is determined, <u>taking into account the availability pattern of the intermittent renewable in question</u>. For instance, the graph below (Figure 6) illustrates the availability profile of solar power (on the right) that is determined by its natural potential versus the chronological load duration curve (on the left).

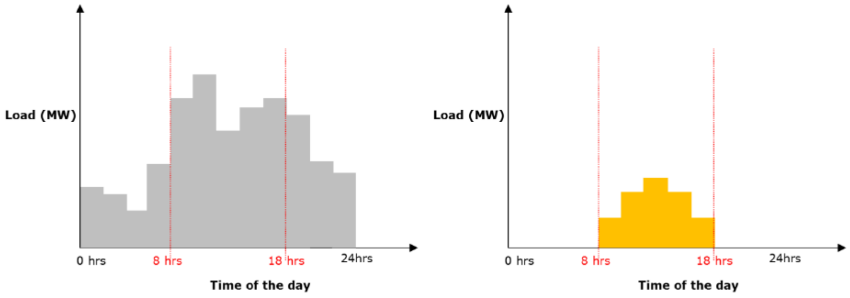

Figure 6 Demand side and PV chronological load duration curves for a representative day

- POTEnCIA introduces a number of mechanisms so as to treat renewables as an integral part of the power system. As mentioned, more simplified approaches may expect renewables either to contribute mainly to base load regimes, or their contribution is subtracted from the chronological load duration curve faced by electricity generators. Mimicking real life system operation, "POTEnCIA determines the extent to which intermittent renewables contribute to the different load regimes based on economic criteria under constraints of availability while taking into consideration the types of power plants that are replaced by them. In that context a flexible allocation of intermittent renewable energies takes place in the model accounting for the opportunity costs induced in the competing, traditional technologies. Of course as described earlier, the constraints concerning the potential contribution of intermittent renewable energies, which has been determined as a result of their load pattern and the chronological load curve of the representative day, are respected. Therefore, in POTEnCIA the power demand load curve is not by default altered due to renewable energies. Instead, intermittent renewable energies are being considered within the dispatching problem as a whole, alongside other power generators."

Peer review report: "Mandatory production requirements are also introduced, thus reducing the flexibility of the electricity system significantly. In particular, electricity generated from cogeneration power plants constitute a significant so-called "must-run" contribution, since "for cogeneration power plants it is considered that they are primarily dispatched in satisfying a distributed steam demand curve" ("POTEnCIA model description version 0.9", p. 66, footnote 41); this leads to minimum electricity production requirements, the so-called "must-run". Other mandatory production includes quotas set by policies, e.g. generation from biomass or variable renewables."

- POTEnCIA offers the option to introduce minimum production requirements in order to reflect considerations linked to
    - "Quotas set by policies (e.g. electricity generation from biomass)
    - Electricity generated from cogeneration power plants
    - Intermittent renewable energy forms for which priority dispatching is assumed
    - Possible limitations related to installed capacities (e.g. nuclear power plants) or the existence of indigenous energy sources (for example lignite, coal etc.)." (p66)
- Of course, if no such considerations are assumed in the scenario setting, the entire chronological demand load curve is met on the basis of an economically driven dispatching across load regimes. On cogeneration please see comment on point annex 2 - 3.2 below.

Peer review report: "With respect to capacity planning and investment, the model is able to distinguish between three different behavioural assumptions, i.e. 1) individual dedicated producers that have no concern for system costs; 2) multiple market agents with heterogeneous behaviour; and 3) a central decision planner. The traditional perfect-foresight-optimization with perfect information is replaced by foresight with imperfect information and a strong role for expectations, e.g. concerning the likelihood of certain policies, such as ETS, efficiency, renewables, etc. In identifying investment needs, POTEnCIA uses the same approach as for operation of the system, catering to conventional fossil-fuel and nuclear energies, through the "market acceptance factor"."

- The same applies here as in the above. A market acceptance factor is only one element influencing the investment decision.
- More specifically, in capacity planning the "market acceptance factor reflects deviations from economic optimality, which occur as a result of the availability of domestic resources and existing infrastructures. In addition, a scenario specific element is introduced to capture possible changes in investors' behaviour as a response to the policies assumed."(p71) This means that the market acceptance factor is set to one except to reflect the unavailability of technologies, resources or infrastructure.

Annex 2 – point 3.1

Peer review report: "If maintained as such, the strength of the model, i.e. the identification of the electricity mix "by hand" through the choice of behavioural and market acceptance factors, will turn *out to be a weakness of POTEnCIA, as it is not capable of dealing with disruptive change in the electricity sector, e.g. the breakthrough of solar photovoltaics as a baseload technology. In combination with the low capability of the model to reflect the dynamics of future electricity systems, POTEnCIA has a tendency to fix the current, relatively inflexible energy mix which largely relies on conventional, fossil-fuels and nuclear power. Even if it is technically possible, the current model set up does not allow for the kind of disruptive change that is already occurring i.e. the emergence of a more decentralized, largely renewables-based system including storage, in the context of a high degree of decarbonisation (80-95% by 2050)."*

- On the use of a multinomial logit formulation and a market acceptance factor we refer to the comments above.
- POTEnCIA allows for the modelling of extreme scenarios with very high shares of RES and strong degrees of decarbonisation. Such scenarios have been assessed jointly with DGs ENER, CLIMA and MOVE. Contrary to the concerns expressed, the set-up of the POTEnCIA model is conceived so as to allow a consistent assessment of such extreme scenarios. To this end, POTEnCIA considers intermittent renewable energies within the dispatching problem as a whole; it "introduces a number of novel concepts going beyond the notion of the 'reserve margin' in order to carefully address the system stability in the power sector" (p72), and captures responses going beyond the economic ones (see above). Moreover, since POTEnCIA allows for the "calculation of the electricity generation costs on an hourly basis", it "makes it possible to endogenously calculate different pricing regimes for distinct users, taking as a basis their hourly demand load patterns". Through this mechanism, it "allows for implicitly addressing, through reflecting the value of load shifting, Demand Side Management policies through changes in the load pattern of the consumption, by energy use."(p73)
- On the flexibility of the model to address disruptive changes in the power sector see comments above.

Annex 2 – point 3.2

Peer review report: "The chosen approach does not correspond to the evolving state-of-the-art of power sector modelling, mainly with respect to the choice of baseload technologies, which is, by definition, composed almost exclusively of conventional plants (Section 3.3.3 "Priority dispatch …", p. 19, as well as Section 5, in particular Section 5.2.3 "Simulation of power plant unit operation", pp. 63 sq.). The inflexibility of the "representative day" approach was deliberately chosen to fit the relevant time dimension of the other sectors; yet it corresponds to a rather static power system analysis that relies almost fully upon conventional generation. In the new context of a largely decarbonized electricity system, the flexibility of the system becomes the main driver, including ramping, storage, etc. In order to capture these effects, a more detailed dispatch and investment model should be run in parallel (see recommendations below). It would be useful to complement the chosen approach ("representative day") by runs of a power market and investment model of much higher granularity of time, including more recent technological options; this "co-model" could produce forward looking electricity mixes, both for the European Union 28 and for each Member State, which could then be used to adapt the individual "market acceptance factors""

- POTEnCIA introduces the notion of a "representative day" to cast the year-long demand fluctuations and resource availability on a single 24-hour dispatch period. Hence, the representative day "provides the most likely load pattern for annual dispatching". The representative day is, however, not inflexible. Instead, "Electricity and steam demand chronological load curves, which need to be met through power plants generation, are calculated in POTEnCIA as the aggregate of the demand loads for the corresponding fuel of all individual end-uses (e.g. industrial ovens, cooking, motors, lighting etc.) in the final energy demand sectors. " (p51) Since these demands change over time and across scenarios, the load pattern of the representative day changes also. The transformation of the chronological load duration pattern into load regime is done on a pure mathematical basis. "Changes in the load profile of the representative day (…) can be accommodated with this load structure. For instance, potential shift in the peak hour to another hour, which may occur as a result of the evolution of different end-uses in the future, can be (dynamically) captured."

- The flexibility of the power system becomes increasingly important indeed. To this end, "POTEnCIA allows considering the impact of cycling on thermal power plants' operation, within the different load regimes. In most of the energy models, power generation is modelled based on the assumption of stationary operation of the plants at their nominal or rated power output. However, the rising share of generation from intermittent renewable energies increasingly leads to operating modes that are far from stationary and imply partial loads (ramping and cycling). Hence, it is important to capture the effects caused by such operating modes." "In POTEnCIA, this impact of the operating mode on costs is quantified. It is implemented through the introduction of:
    - an efficiency correction factor that on the one side depends on the duration of each load regime (which in the model is assumed to link to a different number of power plant type specific start-ups) and on the other side on the actual rate of use of the nominal capacity of a unit within a load regime (reflecting part load operation), and
    - a variable O&M cost correction factor that can vary as a function of the hours of operation and the number of ramp-ups. " (p57)
- With respect to the positioning of POTEnCIA in relation to the *" evolving state-of-the-art of power sector modelling",* one should consider the following features of POTEnCIA underlining its innovative (and at the same time economically sound) character, :
    - mimicking a unit commitment and investment approach;
    - quantifying the impacts of ramping and cycling on fuel input, CO2 emissions and costs;
    - dispatching of renewables as integral part of the system while at the same time fully respecting their natural resource availability;
    - bundling of capacities in operation;
    - explicit distinction of units in operation and in reserve;
    - distinction between a unit's contribution in fulfilling the energy needs of a load regime, and its contribution to the load of that regime;
    - capacity planning reflecting distinct types of market agents' investment behaviour;
    - performing of investment decisions under recursive foresight with imperfect information (involving uncertainty as to capture different market agents' expectations) instead of perfect foresight to better reflect real-life conditions;
    - explicit consideration of system stability, including an endogenous link from the dispatching to the capacity planning decision-making;
    - endogenous treatment of electricity imports and exports;
    - calculation of an hourly pattern for electricity costs and prices

Annex 2 – point 3.2

Peer review report: "Some key assumptions further limit the flexibility of the model to deal with technical change: one of them is the fixed steam output of cogeneration plants, which introduces a high share of conventional "must-run" capacities. Today, there are different alternative options to generate steam, e.g. decentralised boilers, or power-to-heat-storage (e.g. from abundant renewables). Another issue is the way the rather general boundary conditions of how the "sufficient capacity" requirement are determined; quantitative results from the NoPol-scenario suggest an average reserve margin of 2 (net installed capacity / peak), which seems to be quite high (and further induces investment into conventional technologies). But this parameter could easily be adjusted."

- POTEnCIA does not introduce a fixed steam output of cogeneration plants. "For cogeneration power plants it is considered that they are primarily dispatched in satisfying a distributed steam demand curve. The electricity output (initially based on a reference steam to electricity ratio for the dispatched power plant units) is then allocated to the appropriate load regimes of the electricity demand curve and is treated as a minimum production requirement with, however, a flexibility in terms of adapting the steam to electricity ratio as to better reflect the characteristics and constraints of electricity demand. " (Footnote 40)

- In POTEnCIA, a cost-based competition between the demand for distributed steam and for steam produced through boilers using all different types of fuels is explicitly captured (Details in Annex I – model structure per sector; general principles in section 4.2).
- POTEnCIA goes "beyond the notion of the 'reserve margin' in order to carefully address the system stability in the power sector. To this end, endogenously derived signals are sent from the dispatching of the power plants to the capacity planning, affecting both the level of investment needs and the attractiveness of competing investment options" (p72).
- As mentioned, the NoPol scenario results were made accessible to the reviewers with the sole purpose of indicating the level of detail of the POTEnCIA output; they do not refer to any realistic scenario.

Annex 2 – point 3.4

Peer review report: "The nuclear cost estimates used in POTEnCIA seem to ignore system costs, in particular decommissioning and waste storage: The capital costs of nuclear power plants (NPPs) are purely private upstream costs, and ignore "social" economic costs, such as damage risk. It seems that they also ignore the full costs of the fuel cycle, in particular the back-end costs of decommissioning and long-term waste storage.2 The estimated capital costs assume a significant increase of deployment, in the period 2030-2050 (+ 22 GW). Given the costs structure of nuclear power, this may be the results of politically determined investments, for which a break-down by country would be useful (both Nuclear III and Nuclear IV generations). The drop of average capital costs of Nuclear IV generation would suggest significant investments into this technology in the 2020s, which may or may not be plausible from today's perspective.

In general, the treatment of nuclear power is very difficult in any technical-economic model, since investments into nuclear power plants (NPPs) have never been carried out based on economic considerations in a competitive market environment. As Davis (2012) and Lévêque (2014) report based on a very detailed account of previous literature, the nuclear industry has so far not been able to prove a purely economic rationale for private investments, and the situation has deteriorated with low natural gas prices (mainly in the U.S.), and decreasing costs of renewables (worldwide). On the other hand, some EU Member States are still planning investments into NPPs. An alternative approach, that would seem to be more transparent, would involve the new investments into NPPs being set exogenously by the modelling team, based on announcements of the Member States (that should be checked for consistency); in a second step, the ensuing dispatch and price results should then be calculated."

- We welcome the effort of the review panel addressing accuracy of the technology costs (some 270 technology options available in the power sector) and comments on the nuclear power plants capital costs.
- POTEnCIA does not model the nuclear fuel cycle nor the cost related to nuclear power. Rather the capital costs assumed in POTEnCIA for nuclear power are based on available studies.
- To the extent that they are known and confirmed, Member States' decisions on phase-out of nuclear power and commissioning of new plants will be exogenously introduced in the model (the same applies for all other power generation options).
- Apart from the considerations of confirmed commissioning and decommissioning of nuclear power plants, their evolution is driven in the model on the basis of economic grounds unless other exogenous assumptions are introduced and clearly stated.

4 Presentations given to the peer-review panel

European
Commission

POTEnCIA

A new EU-wide energy sector model

Seville, 01/03/2016

Joint Research Centre
the European Commission's
in-house science service

Joint Research Centre

POTEnCIA:

Policy
Oriented
Tool for
Energy and
Climate change
Impact
Assessment

BACKGROUND AND MOTIVATION

Energy is a fundamental sector in modern economies, key as a production factor and crucial as element of welfare within the service consumption portfolio.

Energy policy drivers:

- Environmental sustainability (clean air, sustainable resource use and climate stability)
- Security of supply (diversification of supply, reliability of infrastructures, reliance on domestic resources)
- Affordable prices (competitiveness and accessibility to service)

BACKGROUND AND MOTIVATION

Important changes of the energy sector

The sector (and consequently energy and energy related policies) have been experiencing radical changes and new challenges have to be addressed:

- Challenging targets (climate change, energy efficiency)
- Longer perspectives
- Substantial penetration of variable renewable energy sources
- Market integration
- Competitive markets
- Importance of the demand side

➔ existing tools were mainly developed before the change

BACKGROUND AND MOTIVATION

A model of the European energy sector to assess impacts of strategic EU energy-related policy options

In the light of the need for policy support the policy DGs have requested to the JRC to develop, a new modelling instrument conceived, from the beginning, to take into consideration the new challenges that the sector is facing and carry out policy impact assessment with which to support the policy making process:

- Partially financed by DG ENER and DG CLIMA
- Publicly available for discussion with stakeholders
- Fully documented

HOW TO ADDRESS THIS?

Policy assessment not central planning

- Behavioural model
- No perfect markets, no perfect foresight

Capture the domain for energy policies

- Break-down to agents and installations
- Annual time steps
- Full vintages

Transition to a new system and ambitious (long-term) targets

- Increased detail on the demand side, easing the analysis of energy-efficiency measures
- Sophisticated technology dynamics
- Prepared to represent a larger share of renewables

HOW TO ADDRESS THIS?

Conceived to facilitate its coupling with multi-sectoral models to address the overall impact of energy and climate protection policies

European Commission

POTEnCIA

Overview, scope and purpose

Seville, 01/03/2016

Joint Research Centre
the European Commission's
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Joint
Research
Centre

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OVERVIEW

A model of the European energy sector

POTEnCIA is a mathematical model designed to represent the economically driven functioning of the European energy markets

- Assessing the impacts of strategic EU energy-related policy options
- Coping with the increasingly complex structure of the energy market and related policies

Geographical coverage:

EU Member States (and accession countries, neighbouring countries)

Time horizon:

2050 (and beyond) in **annual** steps

MODEL INTRODUCTION

POTEnCIA follows a ***hybrid partial equilibrium*** approach combining

- behavioural decisions
- detailed techno-economic data
- *one year lag* applies for equilibrium prices

Representative agents response captured through *non-linear* causational equations

The output of the model consists of

- detailed energy balances and related CO_2 emissions (ETS explicitly addressed)
- energy system costs and prices
- activity indicators and related process CO_2 emissions (where applicable)
- installed equipment capacities, characteristics and rate of use (both for the demand and the supply side)
- dynamic technology improvements by Member State (depending on policy assumptions)

MODEL USE

The model can analyse the effects of:

existing and proposed legislation (EU wide and/or Member State specific) related to energy production and use

- CO_2 emission reduction policies (other greenhouse gases addressed through linking to other modelling tools)
- policies aiming at the increased use of renewable energy sources
- policies focusing on increased efficiency of energy use
- policies promoting the use of alternative fuels
- policies accelerating or delaying technology progress and deployment, as well as introducing standards and/or labelling
- different pricing regimes and taxation policies
- different regimes for the electricity market related to decentralisation and liberalisation
- price peaks caused by scarcity of certain energy carriers
- alternative behaviour of representative agents (both energy suppliers and consumers) affecting both their investment decisions and the use of equipment
- policies related to the development of energy networks (including the impact of modifications in the cross-country interconnection capacities) *foreseen for Autumn 2016*

MODEL USE

The model *cannot*:

- carry out engineering analysis on explicit technological options beyond the level of detail present in the model

  e.g. policies related to eco-design and/or labelling are addressed in an implicit manner

  however, the model **can** provide information on the evolution of the overall characteristics of technology groups that are built in line with eco-design definitions

- capture phenomena that occur in fractions of an annual step

  e.g. random fluctuation in intermittent renewable energy sources supply

  however, the model **can** analyse the impact of such fluctuations through snapshots

- assess energy policy impacts on the economy

  however, the model **can** provide quantified information on the impact of such policies at the level of activity

- address issues related to spatial information and representation

  e.g. electricity and gas grids topology, wind parks locations

  however, the model **can** capture the volume and investment cost for networks capacities expansion at country level

IMPLEMENTATION OF POLICIES

POTEnCIA can address both **explicitly** defined policies and those that are **implicit**, including not yet defined future policies

Explicit policies are directly assessed in the model

- Policies related to energy taxation
- Policies related to support schemes for the replacement of installed inefficient equipment (e.g. subsidies on capital costs of cars)
- Minimum efficiency standards for technology options
- Financial support policies
  - *Feed in tariffs*
  - *Investment incentives*
  - *Low interest loans*
  - *Tax reductions*

IMPLEMENTATION OF POLICIES

Implicit policies that link to meeting a certain target

- They are addressed through the *dual value* (shadow price) of the corresponding constraint

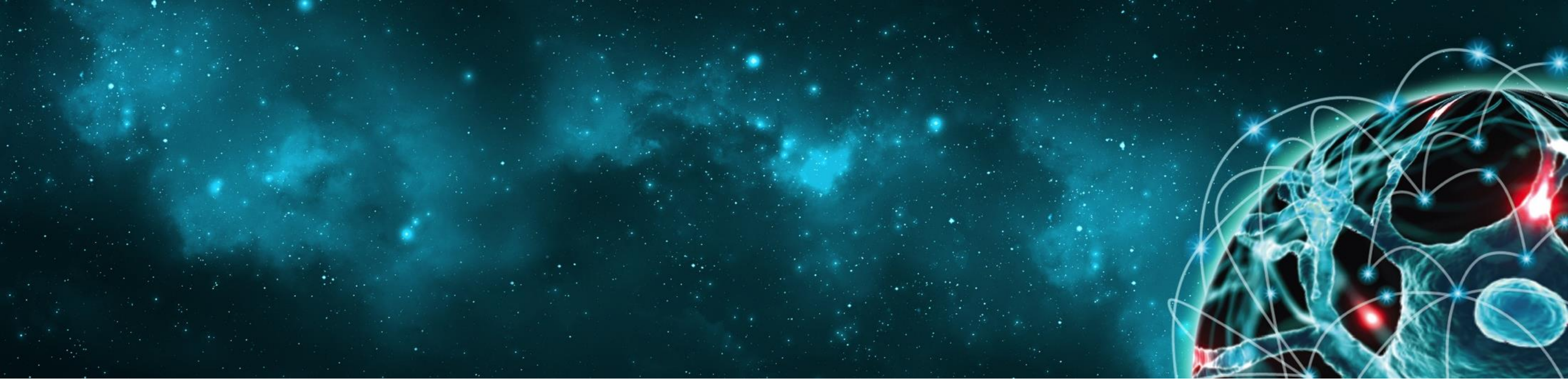
- This dual value acts as an incentive on the decision-making concerning
  - *the investment in new energy equipment, and/or*
  - *the operation of the installed equipment*
- Depending on the policy the dual value may give rise to additional costs
  - *for example auctioning for the ETS versus introducing a carbon value for the non-ETS sectors*
- The effort required in meeting the specific target can be reflected and quantified
- The dual value may be restrictive even in the case that the policy options have a positive NPV

ASSESSING EU ENERGY SYSTEM POLICIES

Energy Efficiency	Renewable Energy	CO_2 Emission Reduction
Technology oriented policies (e.g. efficiency/emission standards)		

ASSESSING EU ENERGY SYSTEM POLICIES

Energy Efficiency	**Renewable Energy**	**CO_2 Emission Reduction**
Technology oriented policies (e.g. efficiency/emission standards)		
Price driven policies (e.g. feed-in tariffs, investment incentives, financial support schemes)		
Quantity based policies (e.g. quota obligations, emission reduction targets, efficiency targets)		
Efficiency value	Renewable support value	Carbon value ETS price
Policies aiming at behavioural changes		
Labelling, consumers awareness	Removing non cost barriers	Carbon footprints
Specific policies		
Policies to accelerate the turnover of stock	Promotion of self-consumption	Average CO_2 emissions standards for new vehicles
	Dispatching rules	



Thank you for your attention

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European
Commission

POTEnCIA

Model features and characteristics

Seville, 01/03/2016

Joint Research Centre
the European Commission's
in-house science service

Joint
Research
Centre

POTEnCIA

Policy
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INTRODUCTION

POTEnCIA incorporates a number of ***features*** and ***concepts*** to assess the various *potentialities* of the energy sector with regards to its evolution over time

Defining the model character

Affecting investment decision and operation of equipment

Capturing multi-faceted responses of energy users to policy regimes

> *Actuality is to potentiality, Aristotle tells us, as "someone waking is to someone sleeping, as someone seeing is to a sighted person with his eyes closed, as that which has been shaped out of some matter is to the matter from which it has been shaped" (1048b1–3).*
> *http://plato.stanford.edu/entries/aristotle-metaphysics/#ActPot*
>
> El ser no sólo se toma en el sentido de sustancia, de cualidad, de cuantidad, sino que hay también el ser en ***potencia*** y el ser en acto, el ser relativamente a la acción.*(Aristóteles, Metafísica, libro IX, 1).*
> *http://www.webdianoia.com/aristoteles/aristoteles_meta_4.htm*

They are distinguished between

- Generic model ones
- Demand side specific
- Power generation specific

GENERIC MODEL FEATURES AND CONCEPTS

REPRESENTATIVE ECONOMIC AGENT

Summarises the individual choices of various decision-makers in a sector

Investment decisions and operation of equipment modelled at the level of the representative agent

Each choice is treated as a 'physical entity'

- Number of agents explicitly defined
- Different representations apply across sectors
  - *The installed equipment needed for the production of one tonne of steel*
  - *The installed heating uses equipment of a household*
  - *An electric appliance*
  - *A car*
  - *A power plant unit*

Explicit representation of idle equipment or installations

Avoiding erroneous allocation of equipment

Allows identifying the domain for policy implementation

Explicit link between the level of use and the characteristics of the equipment/installation (vintage-specific)

ANNUAL TIME STEPS AND VINTAGES

Investment decisions occurring at each point in time form a vintage identified by

- the installation (and its characteristics)
- the number of installations

An installation is defined at the level of the representative agent

- a cluster of energy equipment

  A steel production unit, a household, but also a car

- with specific techno-economic and structural characteristics
- its lifetime is equal to the longest lifetime of the underlying energy equipment

Multiple options of installations are available within a vintage

- Newcomers choices are driven by economic criteria

Vintage-specific characteristics dynamically evolve over time

- Not all equipment have the same technical lifetime
- Adoption of non-energy related equipment options is possible throughout the lifetime of a vintage (accumulating effects)

CAPTURING BEHAVIOURAL CHANGES

Market acceptance factor

- Reflects deviations from economic optimality (exogenous)
  - *Taking into account market agents preference and risk considerations*
  - *Existing limitations of technical and infrastructure nature*
- Endogenously driven adaptation element that reflects market agents behaviour response
  - *Adjustment in relation to changes in purchase power and/or budgetary constraints (reflecting different dynamics across MS)*
  - *Learning by adopting effect*
  - *Changes in response to non-economic signals obtained through prevailing policy conditions (e.g. collective behaviour effects)*

In the same way it is possible to endogenously consider changes in the economic rationality of investment decision making

i.e. through changes of the elasticities of substitution

Additional formulations for behavioural changes of sector specific nature also apply

These mechanisms limit the need for exogenous interventions when addressing different policy scenarios

SUBJECTIVE FINANCING CAPABILITY

Investment decisions take place on the basis of the ***perceived cost*** of capital

The nominal discount rate

cost of capital financing when assuming unlimited access to capital and no risk aversion

The subjective financing capability

- Reflects access to capital and purchase power
- Addresses risk factors/asymmetric information
- Links to budget constraints (differentiated per MS)

Different formulations for the subjective financing capability are available

- *from being deactivated*
- *to being assumed constant and equal across EU Member States*

For commercial investors the perceived cost of capital is equivalent to the ***WACC*** (weighted average cost of capital)

Investment costs are reported on the basis of the nominal discount rate

FEATURES AND CONCEPTS APPLICABLE TO THE DEMAND SIDE

THE REPRESENTATIVE ECONOMIC AGENT

Defined as to better capture sector-specific characteristics

The number of representative agents evolves over time as a function of macroeconomic activity and demographics

In ***industry*** it represents the installation needed for one unit of output

physical tonnes for energy intensive sectors

tonnes-equivalent for energy intensive sectors with heterogeneous outputs

physical output index for non-energy intensive industries (and ***agriculture***)

The approach retained allows distinguishing between

- *structural properties (product characteristics, raw materials etc.), and*
- *energy related equipment characteristics*

and addressing the potential improvements achievable through

- *energy equipment*
- *non-energy related equipment energy saving options*

The comparison across Member States by means of energy related equipment is made possible

THE REPRESENTATIVE ECONOMIC AGENT

In the ***residential*** the representative economic agent is defined by means of

- a *household installation* for thermal uses (a cluster of space heating, space cooling, water heating and cooking equipment)
- an *appliance/representative device* for specific electricity uses

The concept of a representative device is introduced, defined as a representative package of various appliances

For the ***services*** sector the model considers

- the *representative building cell* for space heating, space cooling, building lighting, ventilation and miscellaneous building technologies
- the *representative consumer* for the other energy uses
  - *capita* as concerns hot water services
  - for catering and commercial refrigeration it is the *frequency of using the service per capita*
  - for street lighting it is the *street lighting point*
  - for ICT and multimedia it is the *representative device*

THE REPRESENTATIVE ECONOMIC AGENT

In the ***transport*** sector, two definitions are used

- the *vehicle* for passenger cars and power two-wheelers
- the *representative vehicle configuration* for all other transport modes

a vehicle that has a certain number of seats/cargo capacity and performs a certain annual mileage that makes its purchase and use justifiable (rational use)

techno-economic characteristics defined as to reflect the representative vehicle configuration

The number of representative agents links to the economy through

- the *vehicle ownership ratio* for private road transport
  - the number of passengers per movement determines the corresponding mobility levels
- the annual *flights per capita* in passenger aviation
- the *service requested per capita* (km/capita) on an annual basis for passenger rail and busses and coaches
- the *freight service requested per unit of GDP* for freight transport

For commercial transport, the number of vehicles links to the *realised level of use*

- the number of passengers per movement
- the tonnes per movement

INDUSTRIAL SECTORS

Energy Intensive	Non-energy intensive
Iron and steel ○ Integrated steelworks ○ Electric arc ○ Direct reduced iron (DRI) ○ Alkaline electrolysis	**Food, Beverages and Tobacco** **Transport equipment** **Machinery equipment** **Textiles and Leather** **Wood and wood products** **Other industrial sectors** *Including:* Mining and quarrying Construction Non-specified industries
Non-ferrous metals ○ Alumina production ○ Aluminium primary production ○ Aluminium secondary production ○ Other non-ferrous metals	
Chemicals ○ Basic chemicals ○ Other chemicals ○ Pharmaceutical products etc.	
Non-metallic minerals ○ Cement ○ Ceramics & other NMM ○ Glass production	
Paper and pulp ○ Pulp production ○ Paper production ○ Printing and media reproduction	

Agriculture treated similar to non-energy intensive industries

RESIDENTIAL

Thermal uses	Specific electricity uses

Thermal uses

Space heating
Space cooling
Water heating
Cooking

Main household types

- central heating with solids
- central heating with diesel oil
- central heating with natural gas
- central heating with LPG
- central heating with biomass and waste
- heat pump households
- electric heating households
- district heating households
- geothermal heating households

43 installation types for thermal uses in households considered

Specific electricity uses

Lighting
White appliances

- refrigerators and freezers
- washing machines
- tumble dryers
- dishwashers

TV and multimedia
ICT equipment
Other electric appliances

SERVICES

Thermal uses	**Specific electricity uses**
Space heating	Street lighting
Space cooling	Building lighting
Hot water services	Ventilation
Catering	Miscellaneous building technologies
	Commercial refrigeration
	ICT and multimedia

Each energy use in the services sector is treated separately

TRANSPORT MODES

<table>
<tr><th>Passenger transport</th><th>Freight transport</th></tr>
<tr><td colspan="2">Road transport</td></tr>
<tr><td>Powered 2-wheelers
Private cars
Buses and coaches</td><td>Light commercial vehicles
Heavy goods vehicles</td></tr>
<tr><td colspan="2">Rail, metro and tram</td></tr>
<tr><td>Metro and tram, urban light rail
Conventional passenger trains
High speed passenger trains</td><td>Conventional trains</td></tr>
<tr><td colspan="2">Aviation</td></tr>
<tr><td>Domestic
International – Intra-EU
International – Extra-EU</td><td>Domestic and International - Intra-EU
International – Extra-EU</td></tr>
<tr><td colspan="2">Coastal shipping and inland waterways</td></tr>
<tr><td colspan="2">Domestic coastal shipping
Inland waterways</td></tr>
<tr><td colspan="2">Bunkers</td></tr>
<tr><td colspan="2">Bunkers – Intra-EU
Bunkers – Extra-EU</td></tr>
</table>

27 private car options considered

REPRESENTING THE SECTORAL STRUCTURE

In each sector an explicit structure is defined

- Formulated by means of a ***nested-tree structure***
  - *flexible implementation across the different sectors*
- Decomposing energy use at the level of
    - *processes*
    - *energy end-uses*
    - *technology options, and*
    - *associated energy forms*
- Reflecting the energy equipment installed as to satisfy the service needs of the representative agent

Aluminium production -Primary	Lighting	Lighting	Lighting - High consumption Lighting - Fluorescent Lighting - LEDs Lighting - Innovative technology
	Low enthalpy heat	Thermal	Low enthalpy heat - Diesel oil Low enthalpy heat - Natural gas Low enthalpy heat - Solar
		Heat pumps	Low enthalpy heat - Heat pump
	Air Compressors	Air Compressors	Air compressors - type 1 Air compressors - type 2
	Motor drives	Motor drives	Electric motor - type 1 Electric motor - type 2
	Fans and pumps	Fans and pumps	Fans and pumps - type 1 Fans and pumps - type 2
	Electrolysis (smelting)	Electrolysis	Electric
	Processing (metallurgy e.g. cast house, reheating)	Processing - Thermal	LPG Diesel oil Residual fuel oil Natural gas
		Processing - Electric	Electric
	Products finishing	Finishing - Thermal	LPG Diesel oil Natural gas
		Finishing - Steam	Solids RFG LPG Diesel oil Residual fuel oil Other liquids Natural gas Derived gasses Biomass Steam distributed
		Finishing - Electric	Electric

REPRESENTING THE SECTORAL STRUCTURE

In each sector an explicit structure is defined

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- Decomposing energy use at the level of
  - *processes*
  - *energy end-uses*
  - *technology options, and*
  - *associated energy forms*
- Reflecting the energy equipment installed as to satisfy the service needs of the representative agent

- The explicit characteristics of an installation span the whole tree
  - *Techno-economic characteristics of the energy equipment*
  - *Infrastructure related characteristics*
  - ***Size*** *of the equipment*

THE "SIZE" OF THE ENERGY EQUIPMENT

It is defined differently across sectors

kW installed

- *industrial uses*
- *all thermal uses in buildings*

A unit

- *for appliances*
- *electric devices*
- *private road transport (vehicle)*

The annual mileage

foreseen for a representative vehicle configuration for all commercial transport modes

For new installations, size evolves over time as a function of

- technical developments (exogenously defined) , e.g. downsizing of boilers
- societal characteristics that apply mainly to equipment used by private consumers
  - surface area of a representative household
  - engine size of the representative car
- the level of adoption of *non-energy related equipment options*
  - implying the need for a smaller installation with regards to energy equipment

The size of the energy equipment in existing installations cannot change unless when normal replacement occurs

INVESTMENT DECISION MAKING

Follows the nested tree structure

- The drivers for the decision making at each level of the tree are
  - *the techno-economic characteristics of the alternative options*
  - *their market acceptance factor*
  - *the size of equipment installed*
  - *the* ***desired level of operation*** *of the equipment*

- Substitutability/complementarity of the options available at each level is explicitly addressed

The shares of the various options, *describing the representative agent decision*, are obtained through a *nested multinomial logit formulation*

The domain of newcomers (new installations) is defined as the

total installations (t)
\- *existing stock (t-1)*
\+ *normal replacement (t)*
\+ *premature replacement (t)*

'DESIRED' AND 'REALISED' LEVEL OF USE

Desired level of use

- *reflects the comfort standard ("welfare target") of the representative agent*
- *links to macroeconomic and demographic assumptions*
- *it also takes into account*
  - *the penetration rate of the equipment*
  - *possible saturation limits*

acts in investment decision making

Realised level of use

- *adjusts the desired level in response to the policy framework*
- *agents flexibility to adapt is explicitly considered*
- *vintage and energy equipment specific*
  - *linking to the technical characteristics*

determines the operation of the installed equipment

Defined by means of:

Hours of operation: All sectors except transport

- in industry and agriculture the technical specificities of the corresponding production process (exogenously defined) determine the operation of the energy equipment
- in buildings no inter-linkage applies across different end uses

Annual mileage: Private transport modes

Occupancy rate/Load factor: Commercial transport modes

ENDOGENOUS TECHNOLOGY DYNAMICS

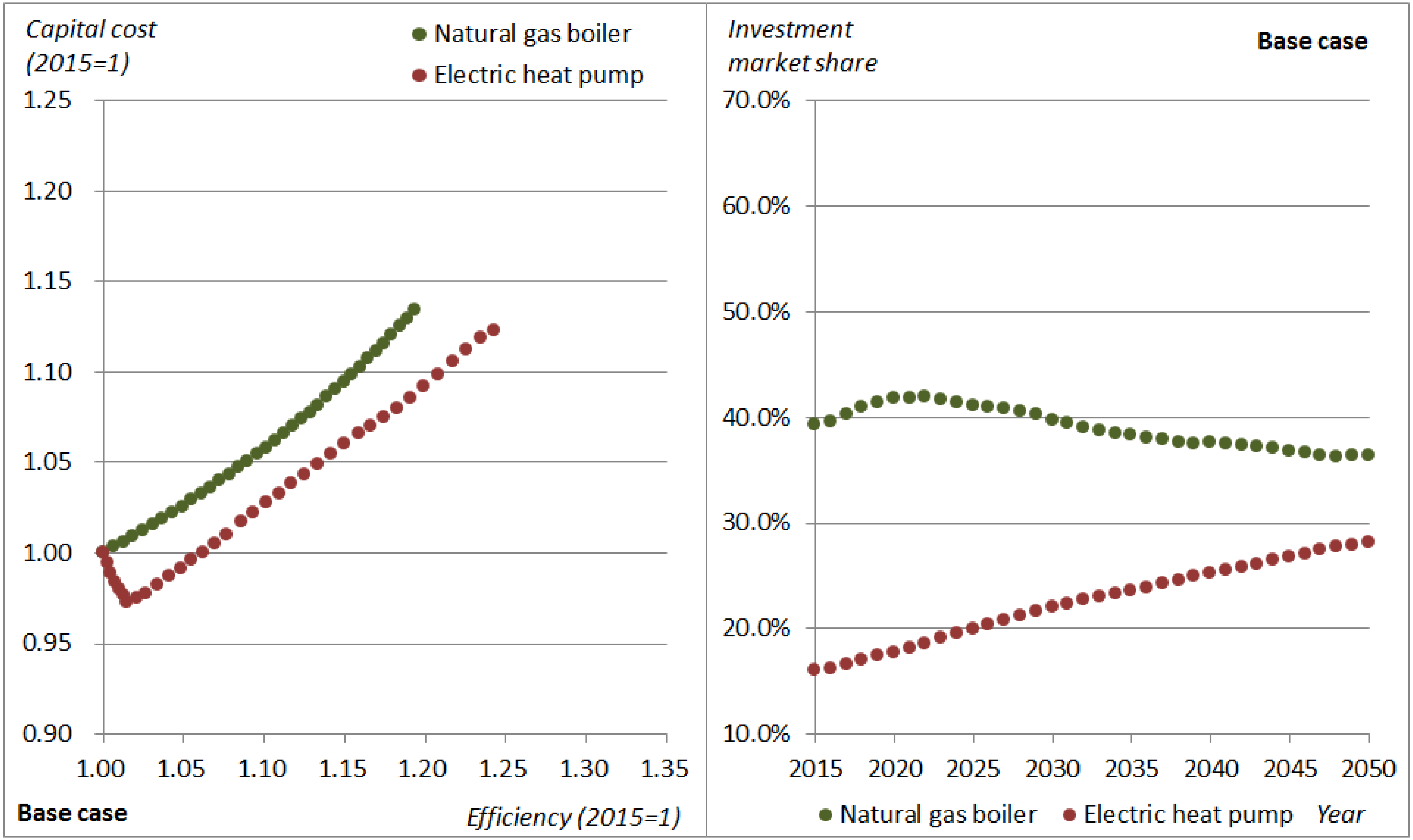
At the level of technology options three technologies choices are available

- Dynamically evolving over time towards a theoretical optimum (backstop)
- The pace of efficiency improvements also links to the deployment of the option
  - *If a technology option becomes unattractive its technology progress slows down*
- The techno-economic characteristics are a function of the distance to the backstop and the pace of moving towards it
- Learning and deployment effects are endogenously captured

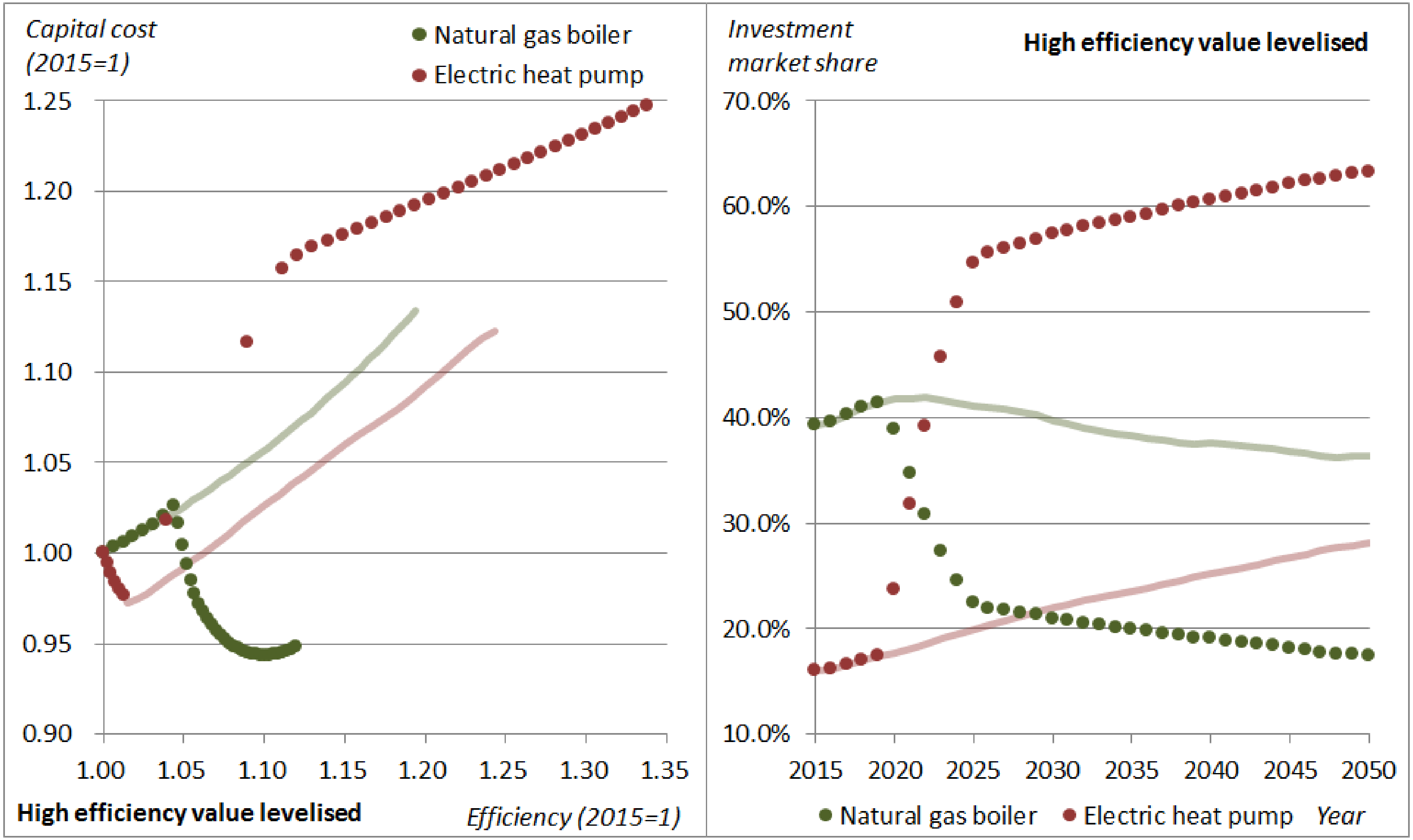
The formulation allows for the explicit representation of minimum standards

Country-specific efficiency characteristics for the existing stock are also reflected on its economic characteristics

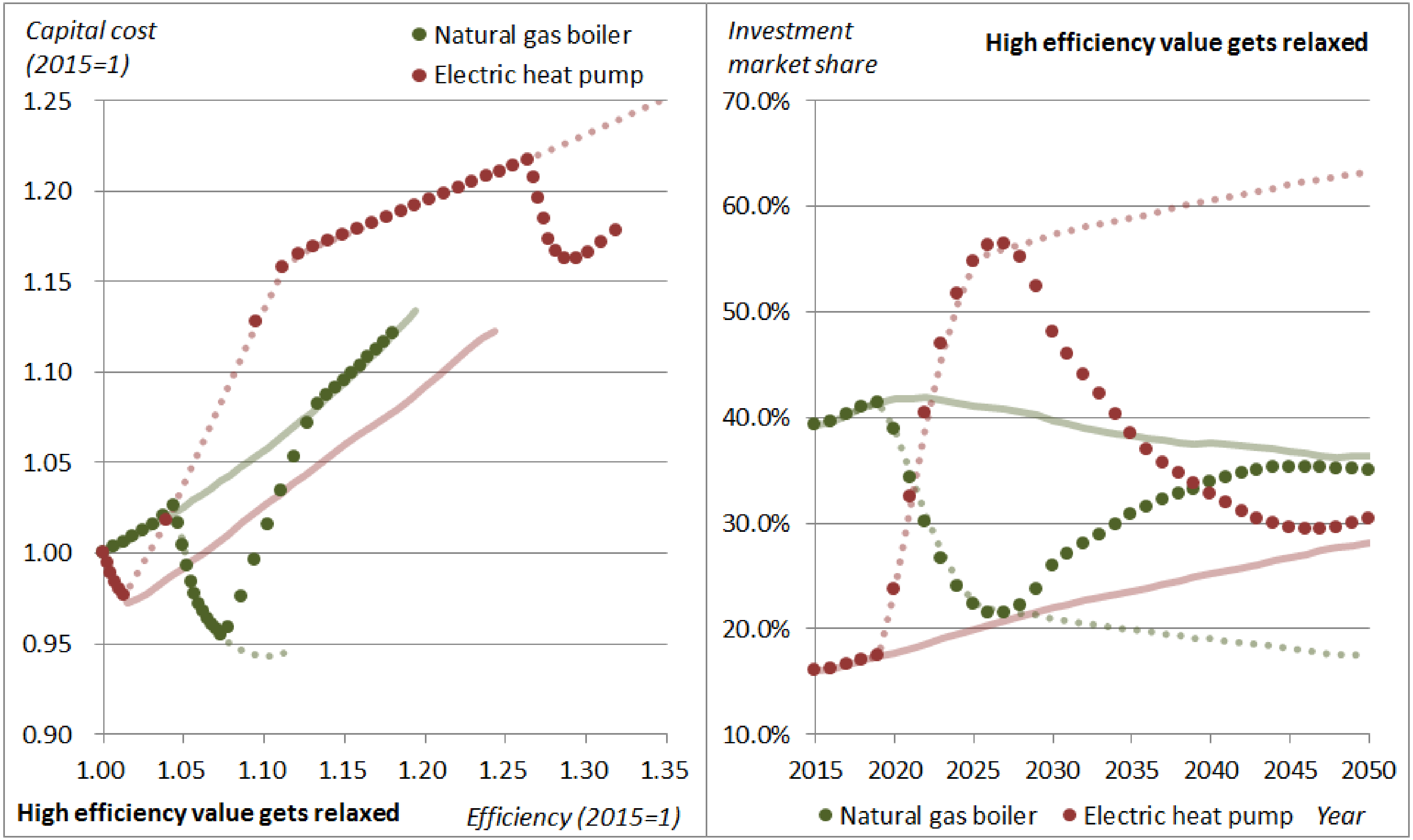
ENDOGENOUS TECHNOLOGY DYNAMICS (AN EXAMPLE)



ENDOGENOUS TECHNOLOGY DYNAMICS (AN EXAMPLE)



ENDOGENOUS TECHNOLOGY DYNAMICS (AN EXAMPLE)



INFRASTRUCTURE EFFICIENCY PARAMETER

The **IEP** reflects investment in non-energy related equipment

Energy saving potential is end-use specific

The level of exploitation of the savings potential is determined by comparing

- *their corresponding costs*
  - non-linear cost formulation that dynamically changes in relation to the already exploited energy saving potential
- *the cost savings occurring from the need for installations of a smaller size and consequently the lower energy consumption*
  - including stranded costs, induced by the underutilisation of the already installed energy equipment

Consecutive (over time) investment in non-energy related equipment options within a specific vintage accumulate to its characteristics

The age of a vintage is also taken into account as to reflect the unwillingness of agents to perform additional investment

- *recently constructed*
- *with a short remaining payback period*

PREMATURE REPLACEMENT OF EQUIPMENT

It occurs at the level of an installation (representative agent)

The decision is based on the comparison of

- the net present value of a new installation plus the induced stranded costs of the equipment that will be prematurely replaced
- the operating costs of the existing vintage for its remaining lifetime plus a fraction of the net present value of the new installation, reflecting the period following the normal replacement of the installed equipment

The current year’s operating costs are considered

The current formulation assumes a direct comparison of costs

- *in the case that the new installation is less costly premature replacement of the existing vintage is performed*
- *alternative formulations (for example in the form of a logit function) may also apply*

Specific policy initiatives can be explicitly introduced (e.g. subsidies on capital costs of cars) as to accelerate the premature replacement

Stranded and policy support costs are explicitly quantified and assigned to the year in which the replacement takes place

THE STRUCTURAL RESPONSE PARAMETER (SRP)

Acts towards capturing structural responses to policy assumptions

Applies on the number of representative agents

which initially links solely to exogenous macroeconomic and demographic assumptions

Driven by changes in the cost of the energy related service

- sector specific, and
- relative to other agents that offer the same service (e.g. passenger transport)

Different interpretations apply across sectors

- in industry and agriculture the SRP can be interpreted as an indicator of changes in the mix and the quality of the output products
  - leading to a revision of the volume of production
  - the sector's productivity (value added per unit of output) also changes
- in the residential sector it implies a revision of the number of inhabitants per household and/or the penetration rate of electric appliances/devices
- similarly, in the service sector it implies a revision in the number of building cells and/or on the intensity of requesting a service by representative consumers
- in transport it reflects
  - changes of the level of mobility within each mode
  - also capturing possible modal shifts in response to prevailing policy conditions

THE BEHAVIOURAL RESPONSE PARAMETER (BRP)

Reflects changes in the agents' behaviour driven by policy assumptions

Applies on the level of use of the energy equipment

Changes considered are of *temporary nature*

- issues related to management and organisation in industrial production
- setting of the thermostat in a building
- changes in the driving style
- improved logistics etc.

It triggers indirect changes in the variable operating costs of an installation

Depending on the policies in place the BRP may act towards further enhancing their effect or partly counterbalancing it

- a taxation policy may not only lead to a lower level of use of the energy equipment but also to a better use of the equipment
- a minimum efficiency standards policy may lead to a less rational use of the energy equipment, which partly counterbalances the related efficiency benefits, as a result of the drop in operating costs

Through the BRP rebound effects can be quantified

IDENTIFYING THE ENERGY SERVICE NEEDS

The energy service needs of a representative agent are the product of

- the size of the different energy equipment options that form an installation, and
- the realised level of use of the corresponding equipment

In each point in time, for each vintage and for all the different formulations of installations, POTEnCIA explicitly quantifies

- the energy service requirements of the corresponding representative agent
- the energy savings obtained through the IEP
- the energy consumed and the corresponding CO2 emissions emitted
- the structural and techno-economic characteristics of the installation
    - *capturing changes in the size of the energy equipment (IEP effect)*
    - *linking to possible normal replacement of parts of an installation*
- the installation-specific fixed and operating costs
- the related cost of investment in non-energy related equipment options (incl. stranded costs of energy equipment when applicable)

  this cost applies at the moment of occurrence, i.e. it is not treated by means of annuities

AGGREGATE FIGURES AT THE SECTOR LEVEL

The corresponding total figures are calculated by *proportionally* allocating the representative agents that operate their installation/equipment across the existing installations in the different vintages

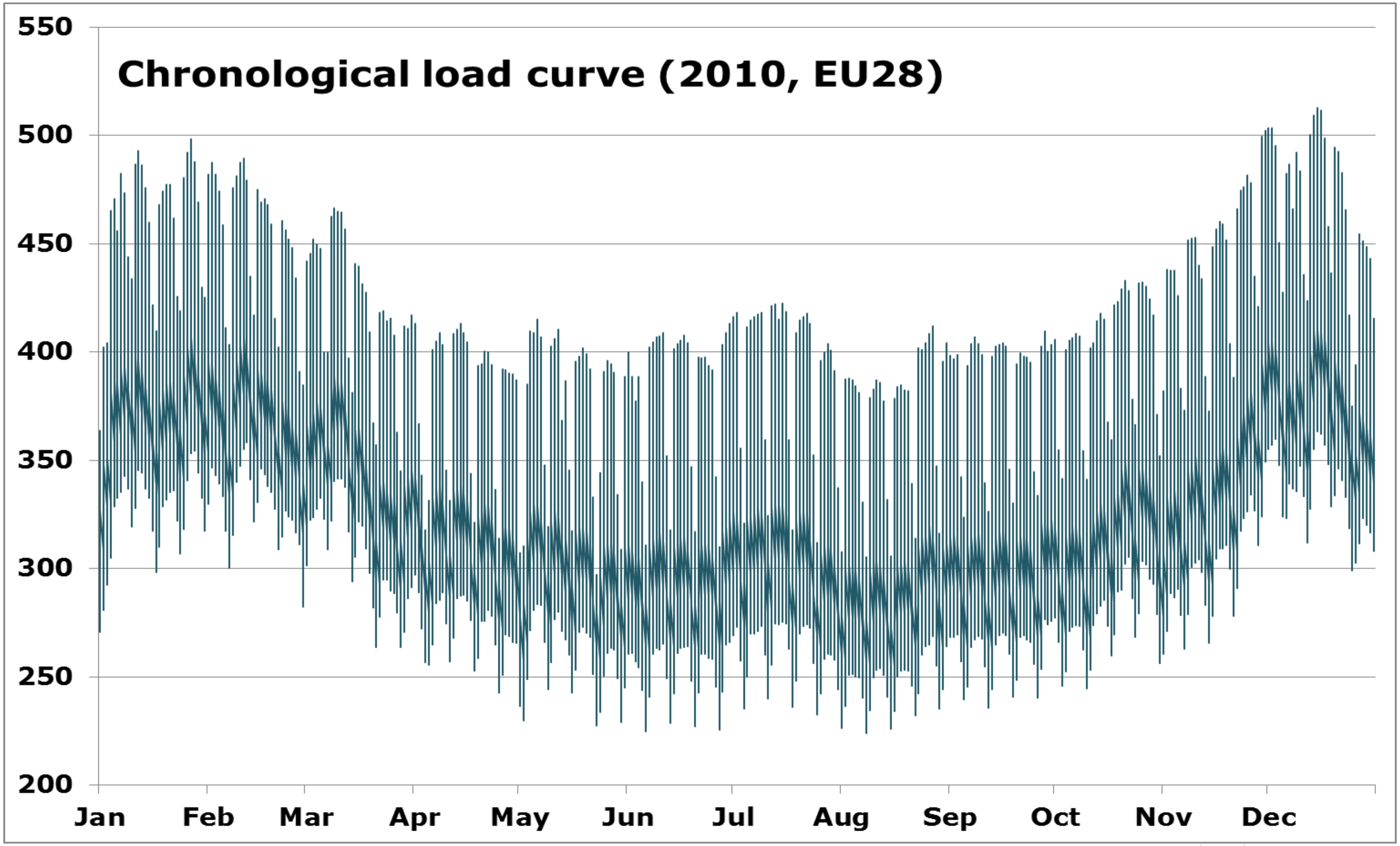
- with regards to total system fixed costs the costs of the idle installations is also taken into account
- costs related to premature replacement of equipment are also explicitly calculated;
  - as in the case of IEP related costs they apply at the moment of occurrence

The explicit characteristics and costs of the different vintages are quantified, but no competition is considered across vintages in POTEnCIA

FEATURES AND CONCEPTS APPLICABLE TO POWER GENERATION

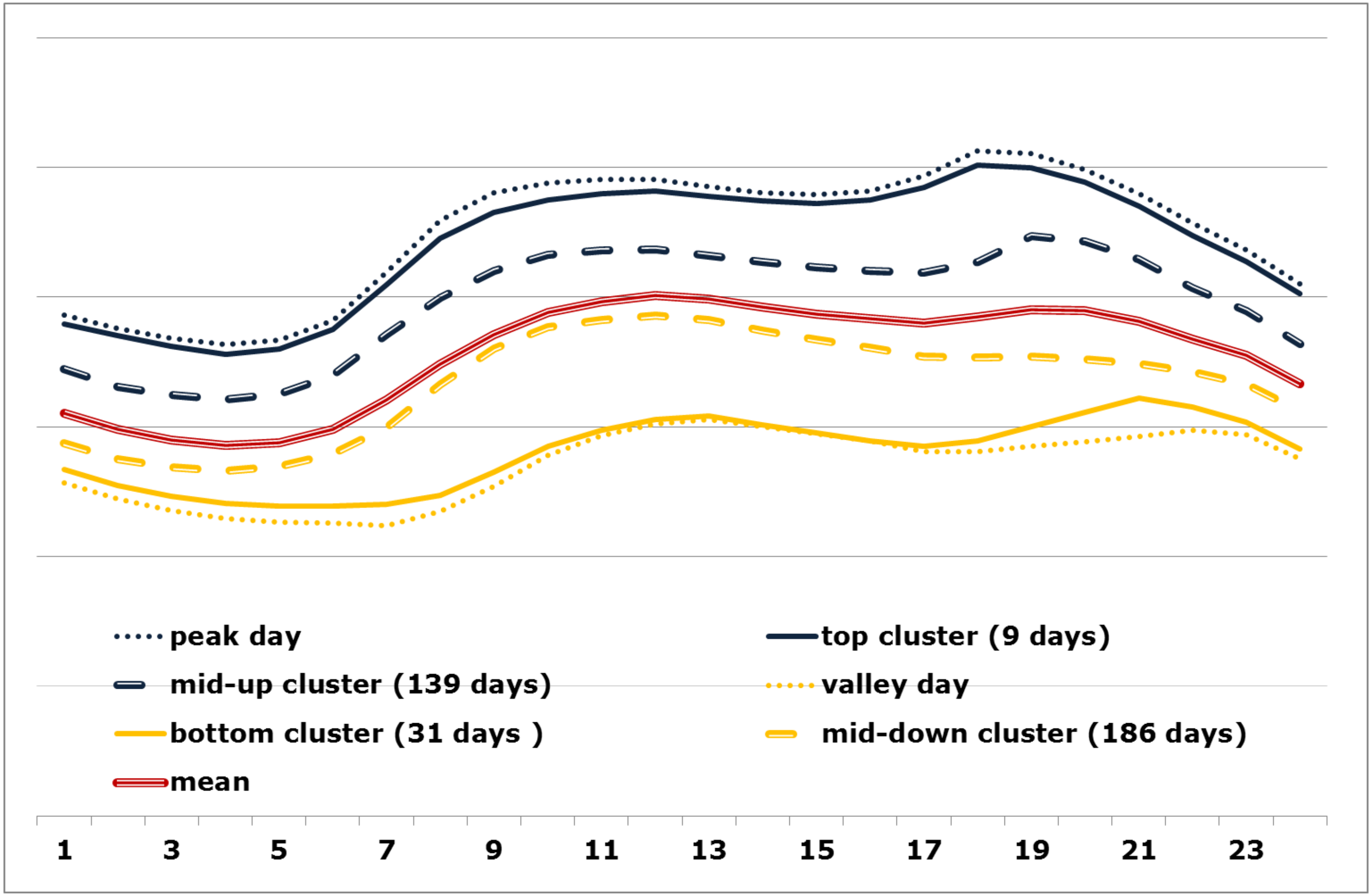
DEFINING THE REPRESENTATIVE DAY'S LOAD

ENTSO-E provides information on an hourly basis for the load (GW)



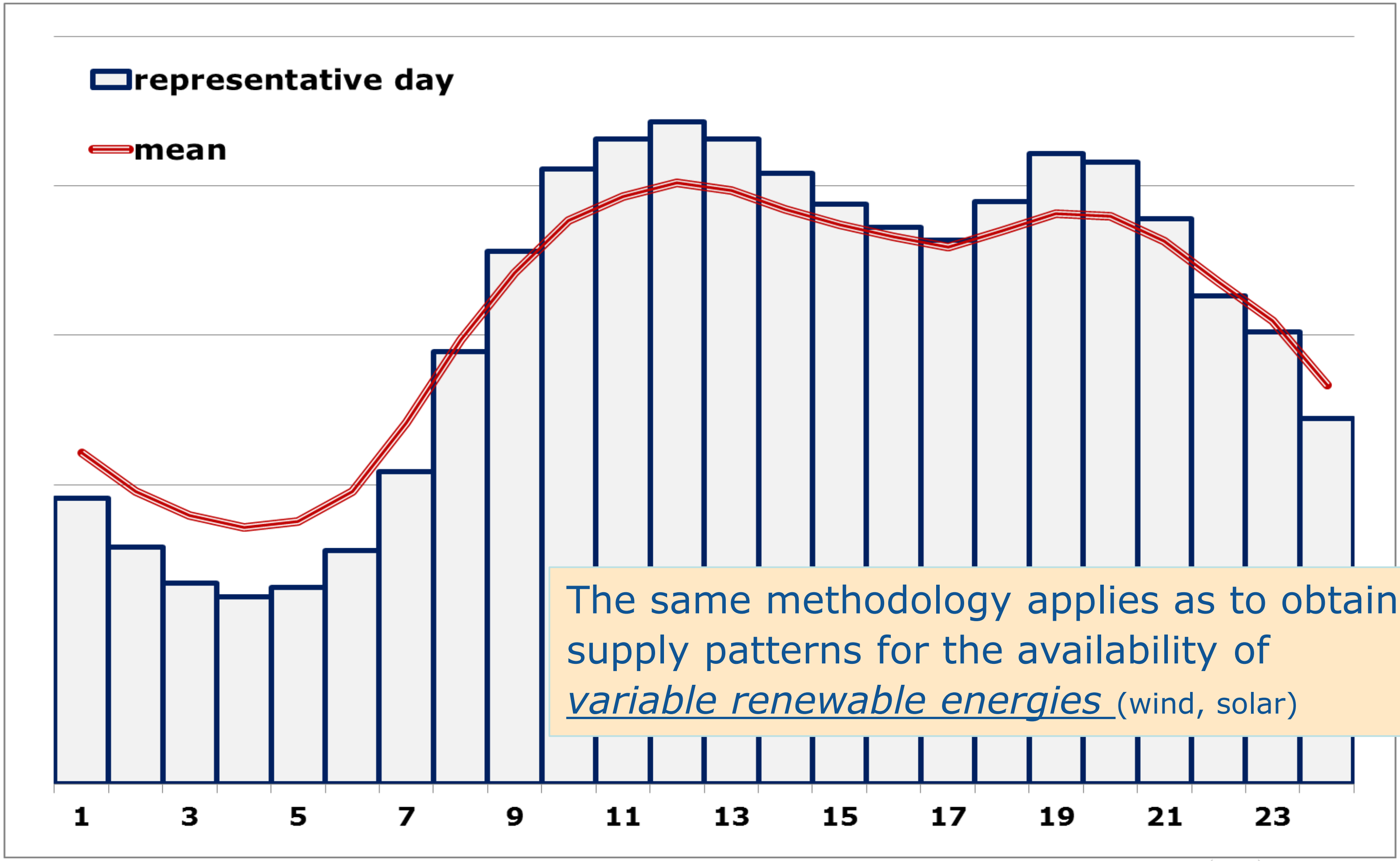
DEFINING THE REPRESENTATIVE DAY'S LOAD

Daily patterns are identified and grouped into ***clusters*** of days (with similar characteristics)



DEFINING THE REPRESENTATIVE DAY'S LOAD

Their frequency of occurrence is used as to obtain the *representative day's load pattern*



The same methodology applies as to obtain supply patterns for the availability of *variable renewable energies* (wind, solar)

LINKING TO THE DEMAND SIDE

In the demand side load *hourly load patterns* are exogenously defined

- Sector and energy end-use specific
- Reflecting the operating regimes of the energy end-uses

The aggregate demand load of electricity is matched to the representative day's load pattern through a *correction factor* (hour of the day specific)

This correction factor is assumed to prevail over the projection period, i.e. it acts in revising the initial load patterns

The future evolution of the shape of the demand load depends on

- changes in the contribution and the technical characteristics of the equipment at the level of end-uses
- changes in the shape of the load patterns reflecting demand side management policies

such changes can be exogenously introduced or endogenously driven in response to *price signals*

LOAD REGIMES

POTEnCIA considers simultaneously both

- the chronological (hourly) load pattern of the demand and
- different load regimes (ranging from the base load to the peak load)

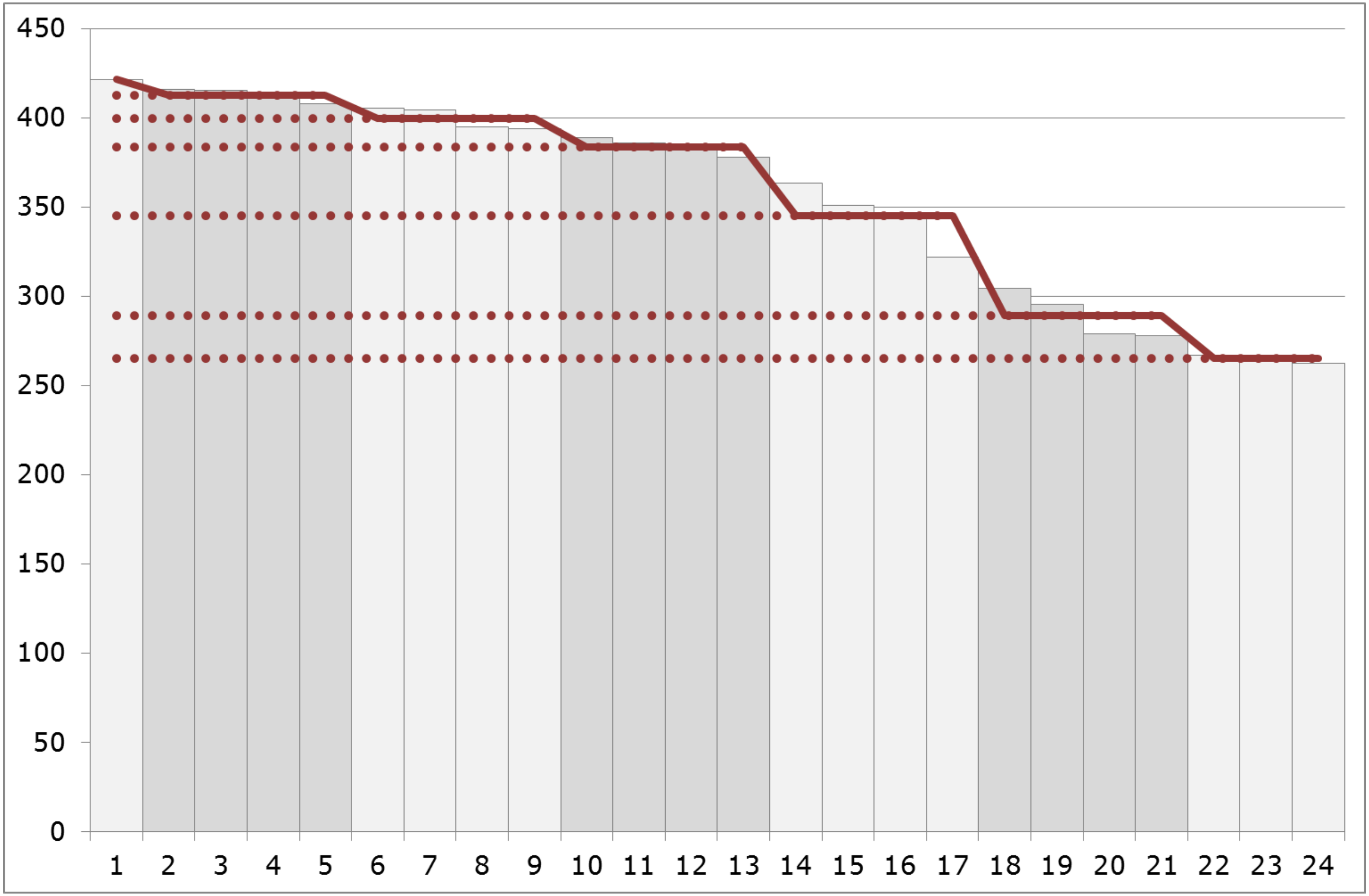
The chronological load curve is transformed into ***load regimes*** for power plants operation

- Re-ordering in a descending order of loads
- Seven load regimes considered
- The hours of occurrence of each load regime apply on the operation of power plants

Load regimes also contribute in identifying and reflecting

- suboptimal operation of power plants (*spinning mode* effects)
- *power plants contribution in in terms of electricity and in terms of load*
  - *e.g. solar power plants operated in base load can only satisfy electricity needs*
- *bundling of units* within a load regime
  - *wind turbines (typically producing electricity for 5-6 hours daily) can be considered as also satisfying load in the base if bundled together*
  - *bundling also applies for thermal power plants (size, type and load regime dependent)*

LOAD REGIMES



TREATMENT OF VARIABLE RENEWABLE ENERGIES

Variable renewable energies (VRES) are considered in POTEnCIA as part of the power plants operation problem

Solar energy, wind energy but also hydro power plants (run of river, reservoirs and pumping)

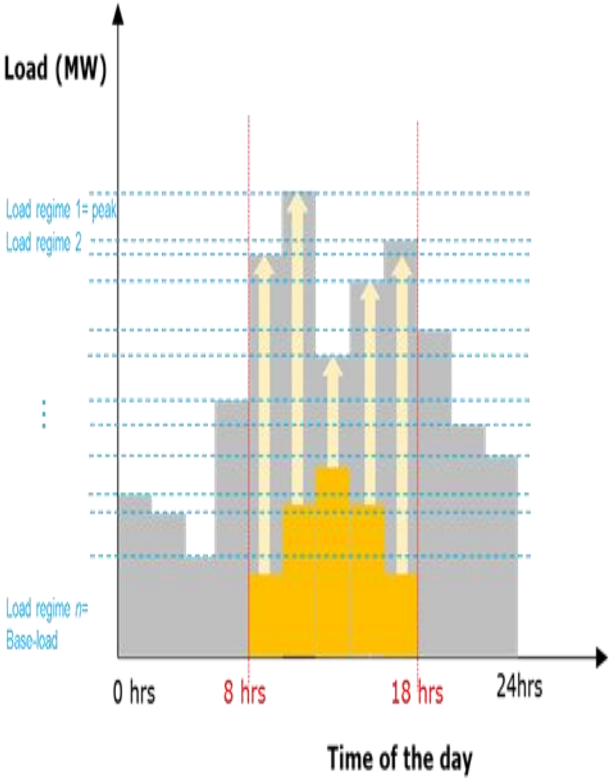
The contribution of VRES in the various time segments and load regimes is based on economic criteria under constraints of resources availability

- accounting for the *opportunity costs* induced in the competing traditional technologies
    - system costs arising from ramping and from spinning of other power plant types
- respecting constraint that reflect the potential contribution of VRES on an hourly basis
- ensuring the power generation *system stability*

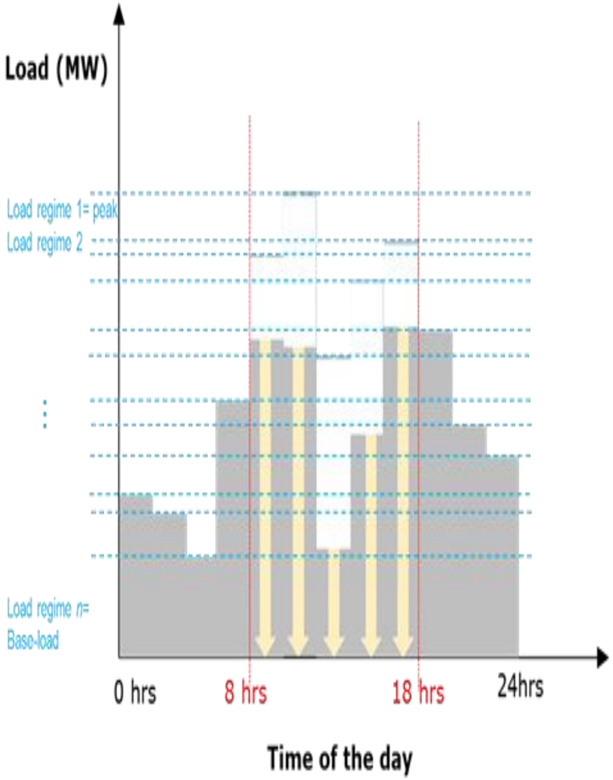
The approach retained allows:

- distinguishing between electricity and load contribution of VRES
    - *Natural availability* patterns are respected
- identifying possible curtailment of VRES
- quantifying the impact of VRES operation on traditional technologies

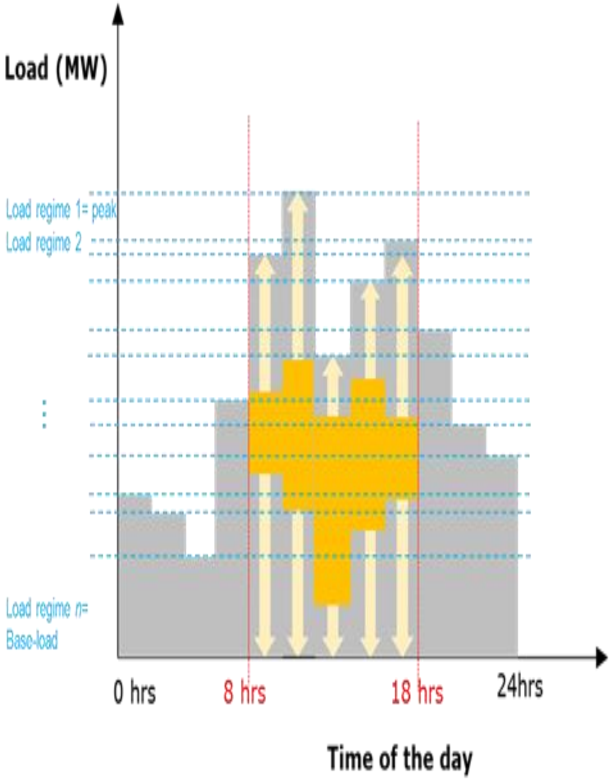
VARIABLE RENEWABLE ENERGIES (AN EXAMPLE)



Strict merit order



Residual Load Curve (RLC)



POTEnCIA

SIMULATING POWER PLANTS OPERATION

Mimicking a **unit commitment** approach accounting for

- the unit's characteristics
  - size (and technical availability)
  - minimum stable load
  - techno-economic characteristics (load regime dependent)
- resources availability constraints
- power plants operation specifications
  - technically optimum hours of operation (reflecting operation with nominal efficiency)
  - giving rise to bundling of capacities for thermal units
- the policy framework

A **portfolio management approach** is followed

- multinomial logit formulation
- load regime specific
- grid operators preference reflected: from pure merit order to a diversified portfolio approach

The adoption of the portfolio management approach allows capturing the variety of similar units beyond the levels of disaggregation in POTEnCIA

THE SIMULATION OF POWER PLANTS OPERATION

The ***dispatching process*** involves four distinct steps

1. Calculation of operating costs depending on the operating mode of the power plant

2. Determination of the “attractiveness” of the different power plant options

   within the different load regimes versus the competing technology options in the same load regimes

3. Explicit ranking order of power plant types

   performed simultaneously across all load regimes and for all power plant types

4. Simulation of the power plant units operation
   - Mandatory production requirements
     - *priority dispatching*
     - *linking to indigenous resources availability*
     - *policy quotas*
     - *CHP electricity*
   - Economic dispatching in meeting the remaining load

POWER PLANTS UNIT OPERATING COSTS CALCULATION

Stationary operating costs

Based on nominal techno-economic characteristics of power plant units

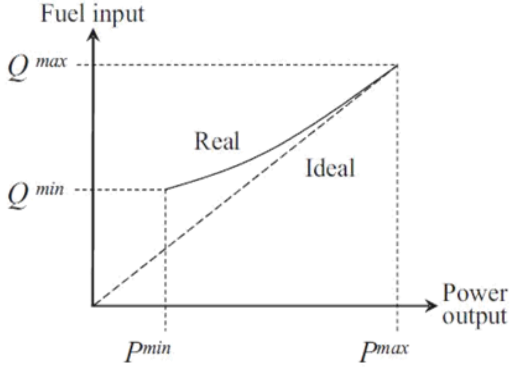
- Power plant efficiency
- Rate of own consumption
- Variable operating cost
- Fuel cost
- Policy costs (ETS price, renewable value etc.)

Operating mode related costs reflecting cycling

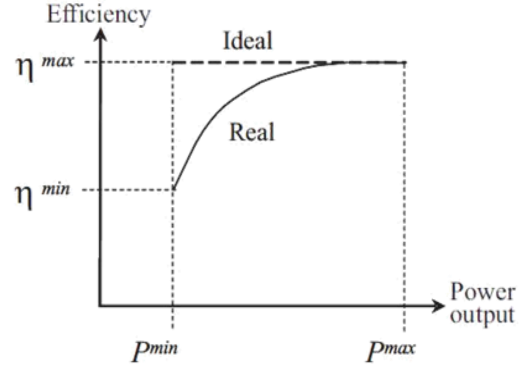
Part load operation (spinning reserve)

Start-ups and shut downs

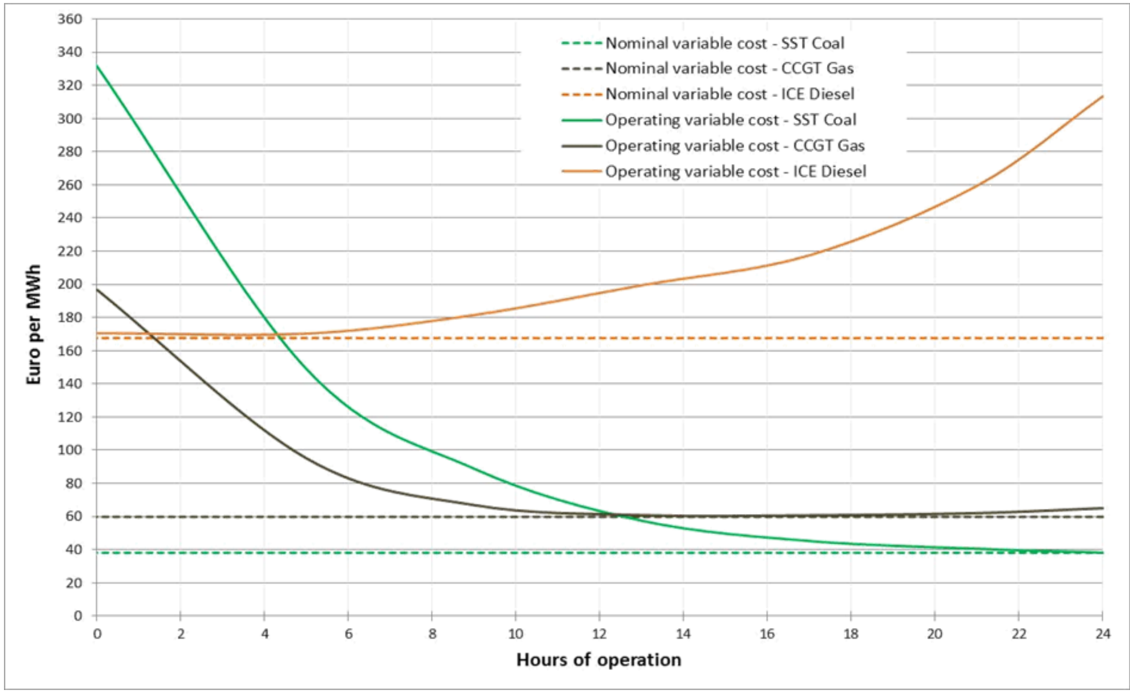
- wearing off of equipment effect
- increased own consumption effect



(a) Real and ideal input-output characteristic



(b) Real and ideal efficiency



DESIRED GENERATION OF POWER PLANTS

The ***multinomial logit function*** gives rise to a *desired market shares* of the various power plant options within each load regime

These market shares can be interpreted as the probability of choosing a certain power generation option compared to the available alternatives

The **desired generation** of a power plant type within a load regime is calculated as the product of

- the desired market share;
- the load of the specific regime; and
- the operating hours attributed to the regime

This means that the desired generation is unconstrained by means of capacity availability, rate of use, fuel and resource availability etc.

The **ranking order** of the power plant types is then determined

- derived through a descending ordering of power plant types desired generation across all regimes

POWER PLANTS OPERATION

Following the ranking order power plants are put into operation

The next constraints are explicitly considered

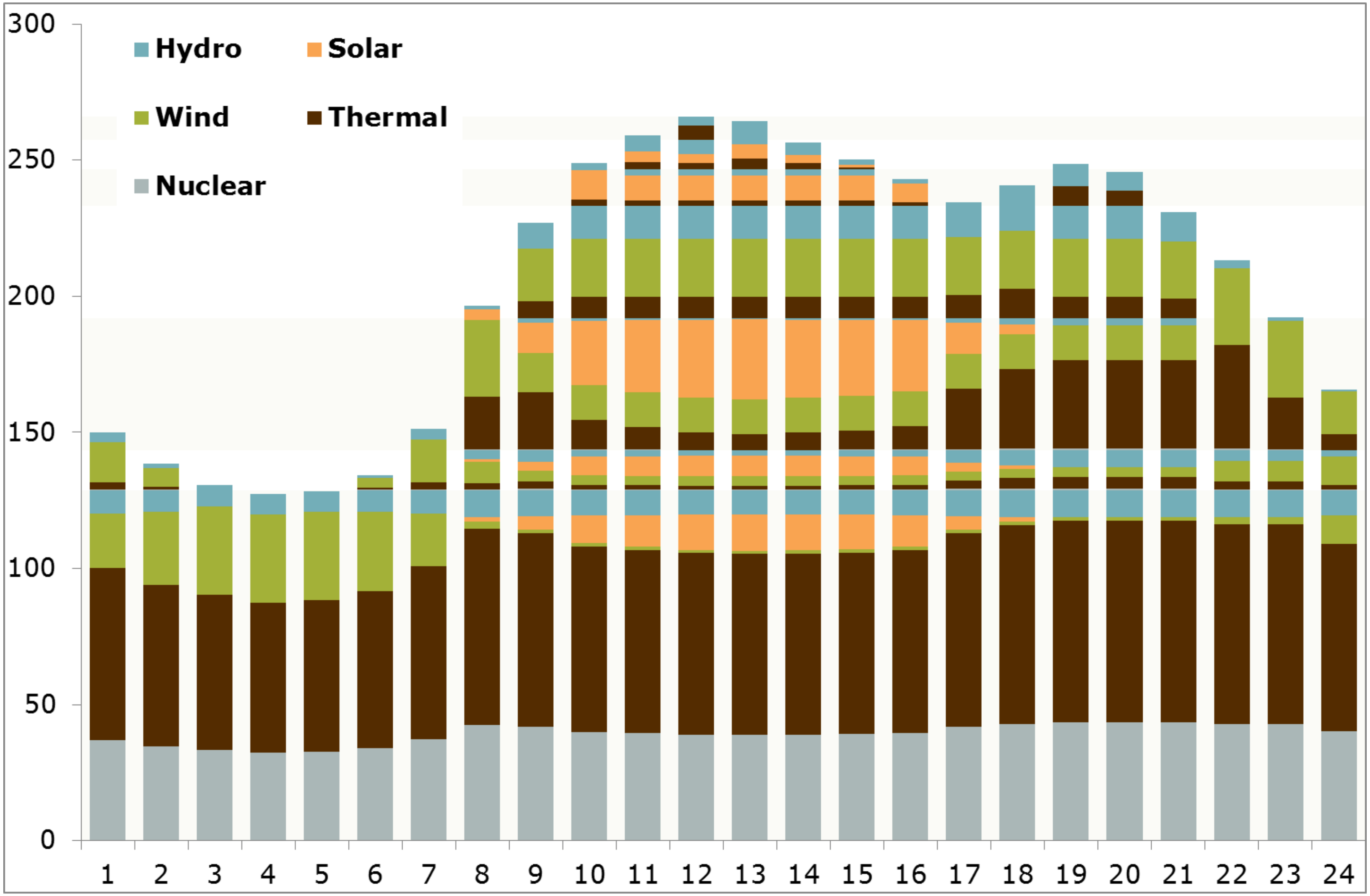
- desired generation
- number of units available
- minimum stable load of operation of a unit
- bundling of units
- resource availability and natural supply patterns

Power plants put in operation may act in satisfying electricity generation only or simultaneously electricity and load

After each step the stock of the power plants option put in operation and the corresponding fuel availability are revised

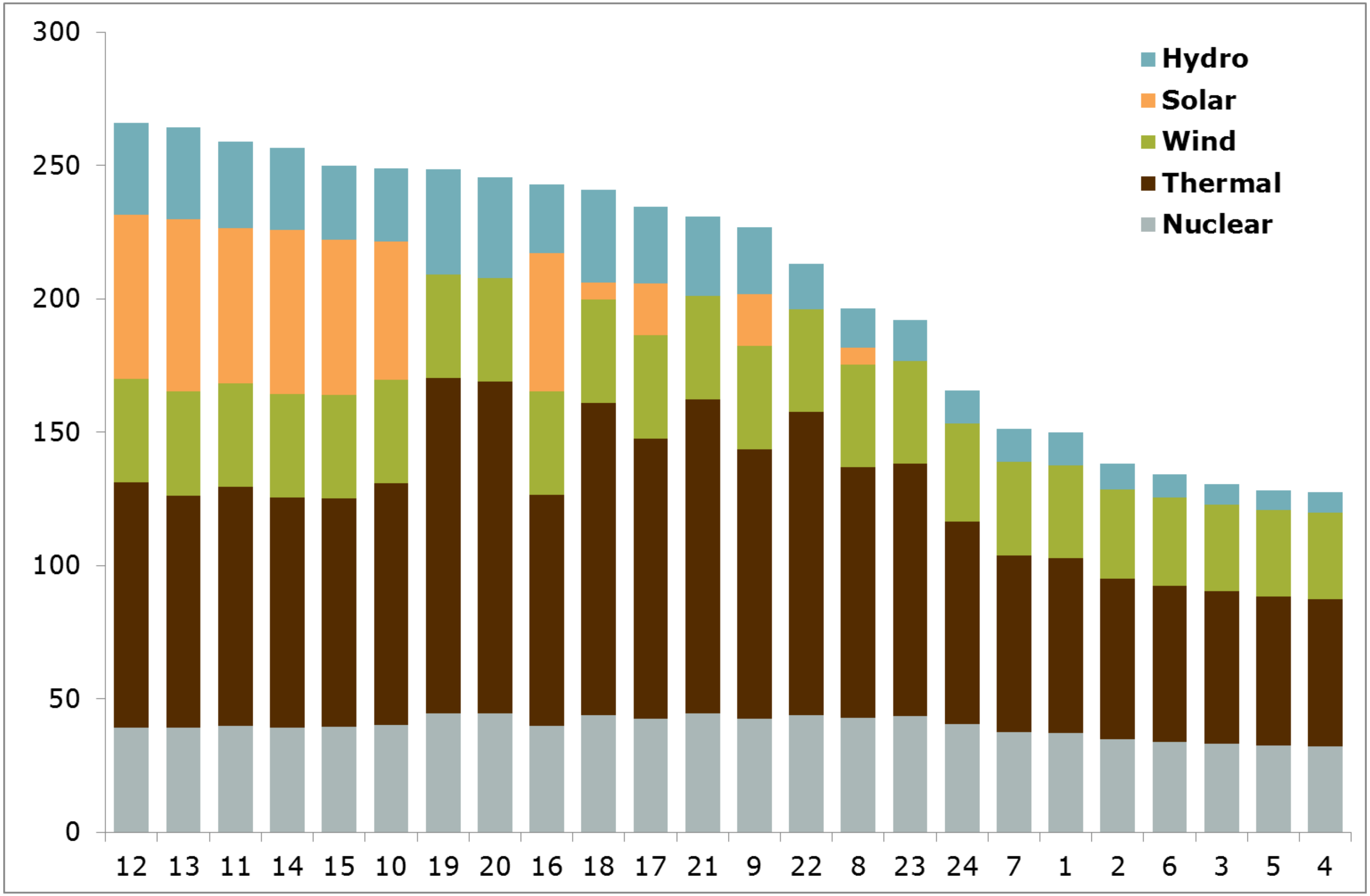
The process is recursive until either satisfying the load or exhausting the available units

POWER PLANTS OPERATION (AN EXAMPLE)



European Commission

POWER PLANTS OPERATION (AN EXAMPLE)



European Commission

POWER PLANTS OPERATION OUTPUT

The methodology implemented allows to obtain information on

- the number of units in operation and the unused ones
- the possible bundling of units within a specific load regime
- the actual hours of use of the units in operation
  - *capturing part load conditions*
  - *spinning mode identified*
- the fuel consumption, CO2 emissions and related operating costs
  - *within each load regime and by hour*
  - *explicit calculation of their quantities stemming from the operation of power plant units in a non-optimal mode*

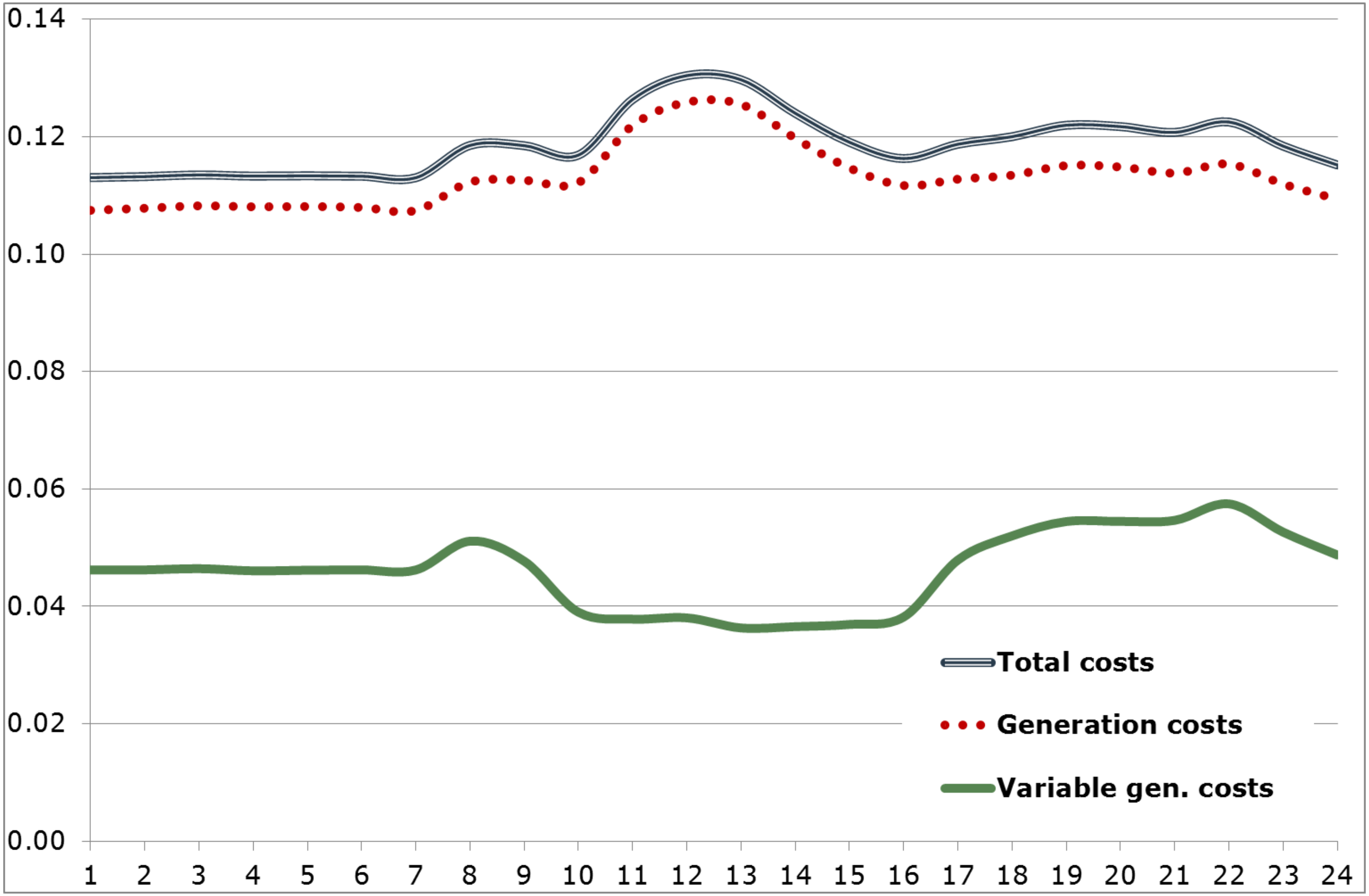
Consumer specific costs calculated assuming full cost recovery and considering their specific load profile

- possible to quantify signals to demand segments towards load shifting (DSM)
- transmission and distribution costs are endogenously quantified (hourly pattern)

Mark-ups apply as to derive the pre-tax electricity prices (tariffs at consumer's level)

End-user prices obtained after applying tax rates

ELECTRICITY GENERATION COSTS (AN EXAMPLE)



CAPACITY PLANNING

Investment takes place in *multiples of unit sizes*

- Mimicking a mixed integer programming approach
  - Strongly affecting the evolution of the power plants park, especially for small countries
- Preferences for delaying or advancing investment can be reflected
  - Linking to the policy regime
- Underinvestment may occur

The load profile of investment needs is defined by

- the load profile of decommissioned capacities, and
- the load pattern of the evolving demand load curve

Market shares in each load regime identified making use of a *nested multinomial logit formulation*

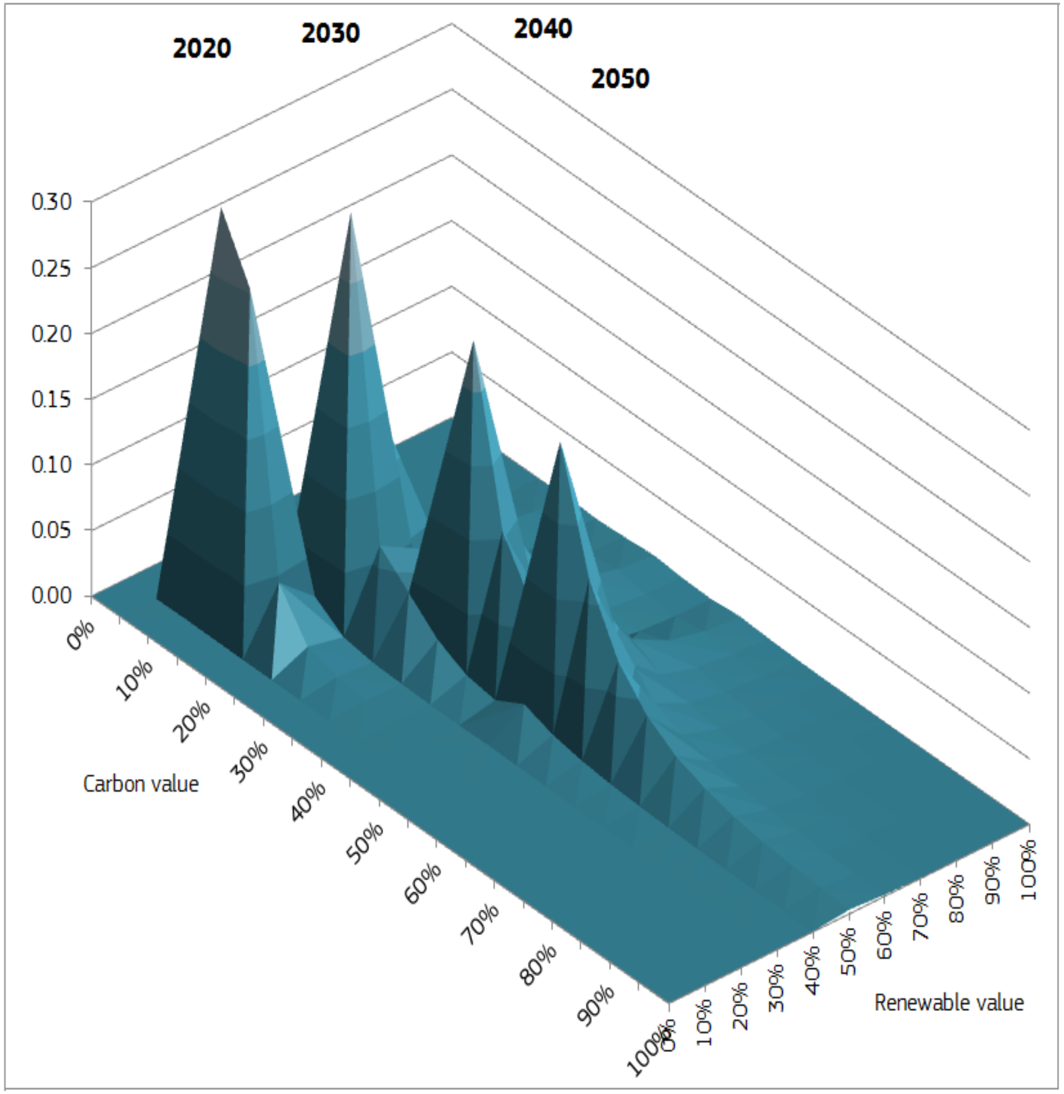
- up to four typical size classes
- technology options
- fuel types
- electricity-only and cogeneration plants
- power plants with/without CCS equipment

DYNAMIC RECURSIVE FORESIGHT WITH IMPERFECT INFORMATION

Capacity planning considers by default uncertainty for the policy framework

For a typical market agent a set of policy options combinations is defined

- The envisaged future policy framework links to prevailing policy assumptions
- The weighted distribution of the expectations of the market agent applies on investment decisions



European Commission

"POINTS OF VIEW" IN CAPACITY PLANNING

Dedicated producers: their decision reflects the fulfilment of a specific load pattern

- *demand or resource availability driven (IPPs fall in this category)*
- *weighted distribution of expectations dealt with by means of number of producers*
- *overall decision obtained combining those of the different load regimes*

Multiple market agents: individual investment choices in view of the overall load profile

- *load regimes decisions form a new problem at the aggregate level*
- *different expectations dealt with by means of number of producers*

Central decision planners: central investment choice in view of the overall load profile

- *instead of multiple individual decisions, one single decision that encompasses various assumptions with regards to the different possible evolutions of the system*

CAPACITY PLANNING OUTPUT

Investment identified by means of units

- size specific
- obtained by applying the aggregated market shares on the capacity needs

The default setting considers the central decision planners option in implementing the investment decision

- Exogenous weights may apply as to define different contributions for the different "points of view"

Economically realisable potentials may be endogenously revised in the presence of specific policy regimes

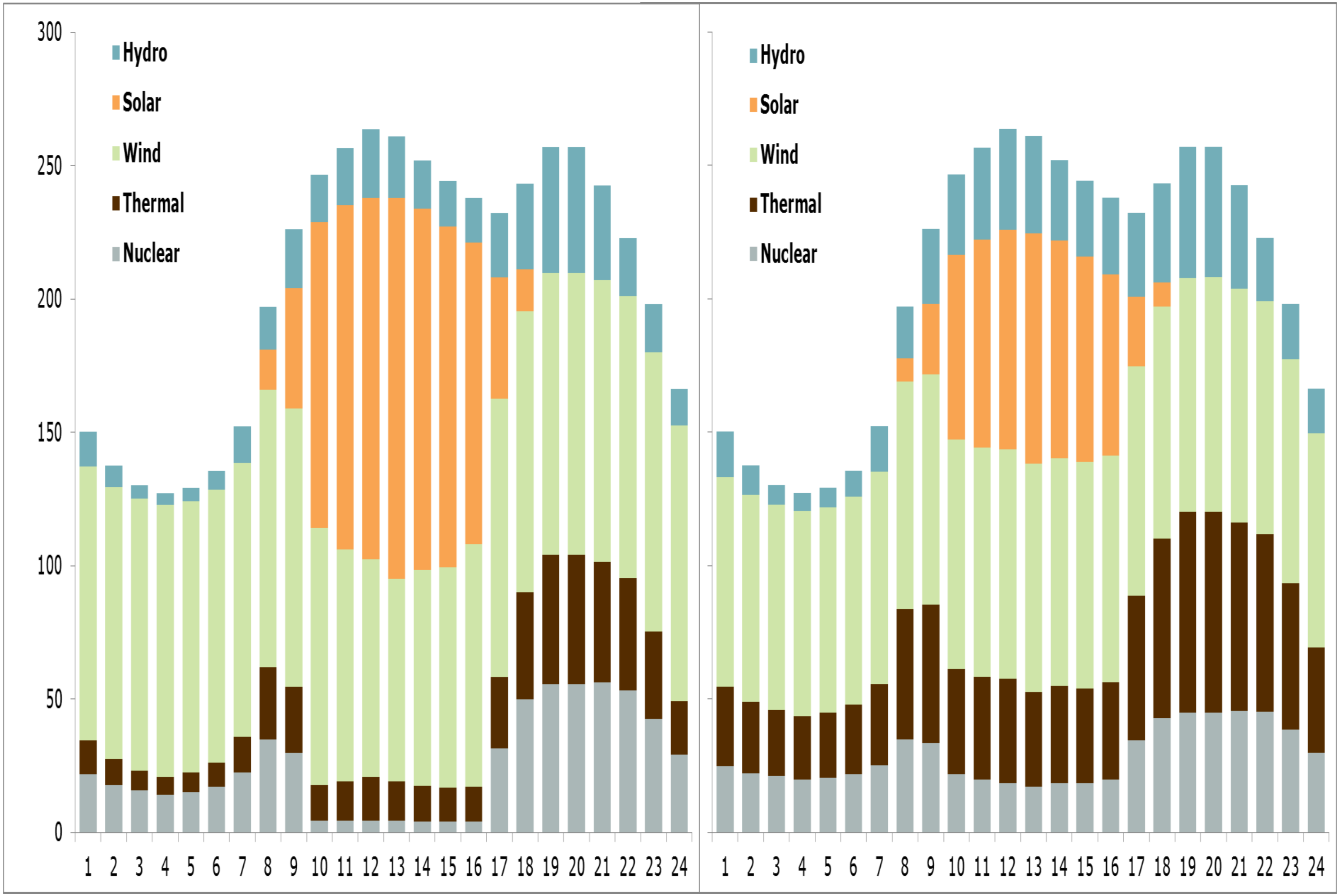
- Technical potentials form the upper limit
- Surpassing the initial economically realisable potential leads to non-linear increase in costs

SYSTEM STABILITY CONSIDERATIONS

Explicit consideration of system stability implemented through

- *Endogenous* calculation of the reserve margin
  - *boundary conditions for the total installed capacity versus peak load apply*
  - *the total capacity in use versus the total capacity installed forms another boundary condition*
- The **system stability indicator** provides a signal to the investment decision-making
  - *defined by means of the capacity in operation compared to peak load*
  - *the attractiveness for power plants that satisfy electricity and not load reduces as the system stability indicator increases*

  i.e. investors favour more power plants options that contribute to reliable load


300
250
200
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100
50
0
Hydro
Solar
Wind
Thermal
Nuclear
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hydro
Solar
Wind
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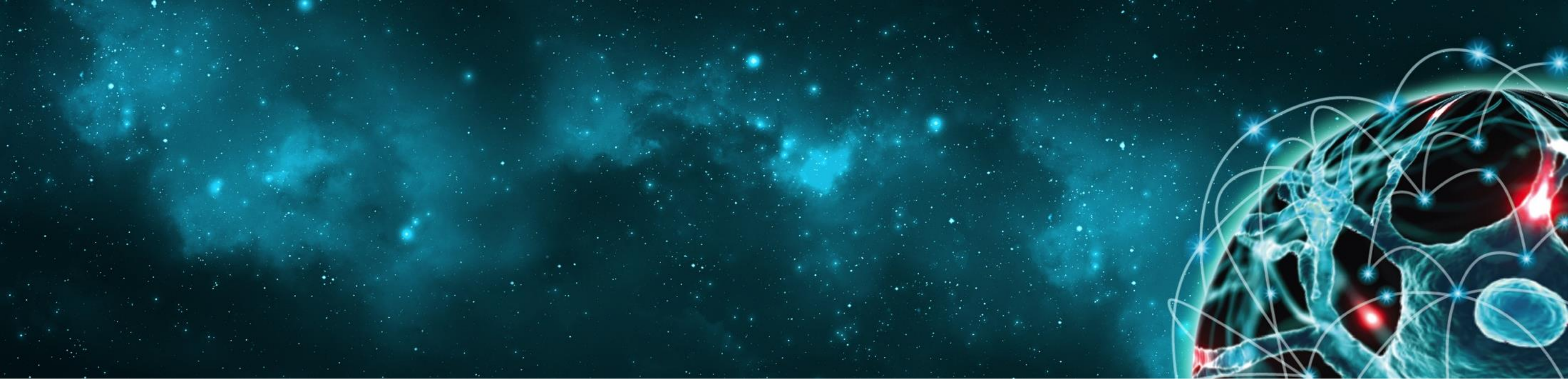
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24



Thank you for your attention

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European
Commission

Introducing the JRC-IDEES database

Seville, 01/03/2016

Joint Research Centre
the European Commission's
in-house science service

JRC-IDEES

Integrated
Database of the
European
Energy
Sector

OVERVIEW

JRC-IDEES is a ***first-of-its-kind database*** that provides a very detailed decomposition of energy use in all sectors of the energy system

Geographical coverage:

EU Member States

Time horizon:

2000-latest statistical year on an annual basis

update with data up to 2014 on-going

ACCESSIBILITY

The database will be made ***publicly available***

- Enhancing transparency to Member States and stakeholders
- Improving the data quality through experts and scientific feedback
- Saving resources by avoiding redundant work on decomposing historical energy data
- Offering a *common reference* that could contribute in
  - better addressing energy futures
  - allowing for improved insights of the impact of historically implemented policies on the energy system

a preliminary version was circulated to experts in March, 2015

KEY FEATURES

By construction, the database *matches Eurostat* data (energy balances, macroeconomic and demographic data, pocketbooks etc.)

Consistent approach throughout all sectors

Takes into account Member States and sector specific characteristics

- the data decomposition within each sector is tailor-made for each country

Explicitly quantifies the contribution of non-energy equipment related factors in meeting energy service

- better identification of the characteristics of energy equipment

Incorporates a very high level of sectoral detail and disaggregation by end-use

- making it usable as input for many different models
- allowing a consistent matching of policies' scopes (e.g. ETS)

Decomposes energy consumption down to the level of one representative agent (e.g. household, appliance, car)

- explicitly distinguishes between technical and behavioural characteristics
- creates a basis for defining the scope for policy action

PRIMARY DATA SOURCES

- EUROSTAT
  - Energy balances
  - Power generation statistics
  - Transport statistics
  - Pocketbook publications
  - Macroeconomic data (nama_nace and structural business statistics)
  - Demographic data
- UN databases (UNFCC National GHG Inventory Submissions, FAOSTAT…)
- U.S. Geological Survey (USGS) Minerals Information Commodity Statistics and Information; European Minerals Statistics of the British Geological Survey
- EURELECTRIC
- EPIC database (installed power plants capacities)
- EurObserv'ER (renewable energy forms)
- Official national surveys and statistics

STUDIES CONSULTED

- EC projects and studies
  - 'Survey on Energy Consumption in Households' (SECH 2010)
  - BPIE, TABULA, ENTRANZE, EPISCOPE on buildings characteristics
  - TRACCS study
  - Preparatory studies of the eco-design for energy using products
  - ODYSSEE-MURE database
  - JRC studies and reports, including
    - BREFS
    - SETIS Technology maps
- IEA reports
- U.S. DOE studies and reports
- Industry associations statistics, studies and reports

RESIDENTIAL AND SERVICES

Characterisation of the energy installation at the level of the representative agent

Thermal uses link to the 'representative building cell' (square meters)

- Installed capacities of energy using equipment
- Explicit techno-economic characteristics
  dynamically evolving over time
- Consumers behaviour (hours of use of equipment by energy use)

Identification of number of households by cluster type

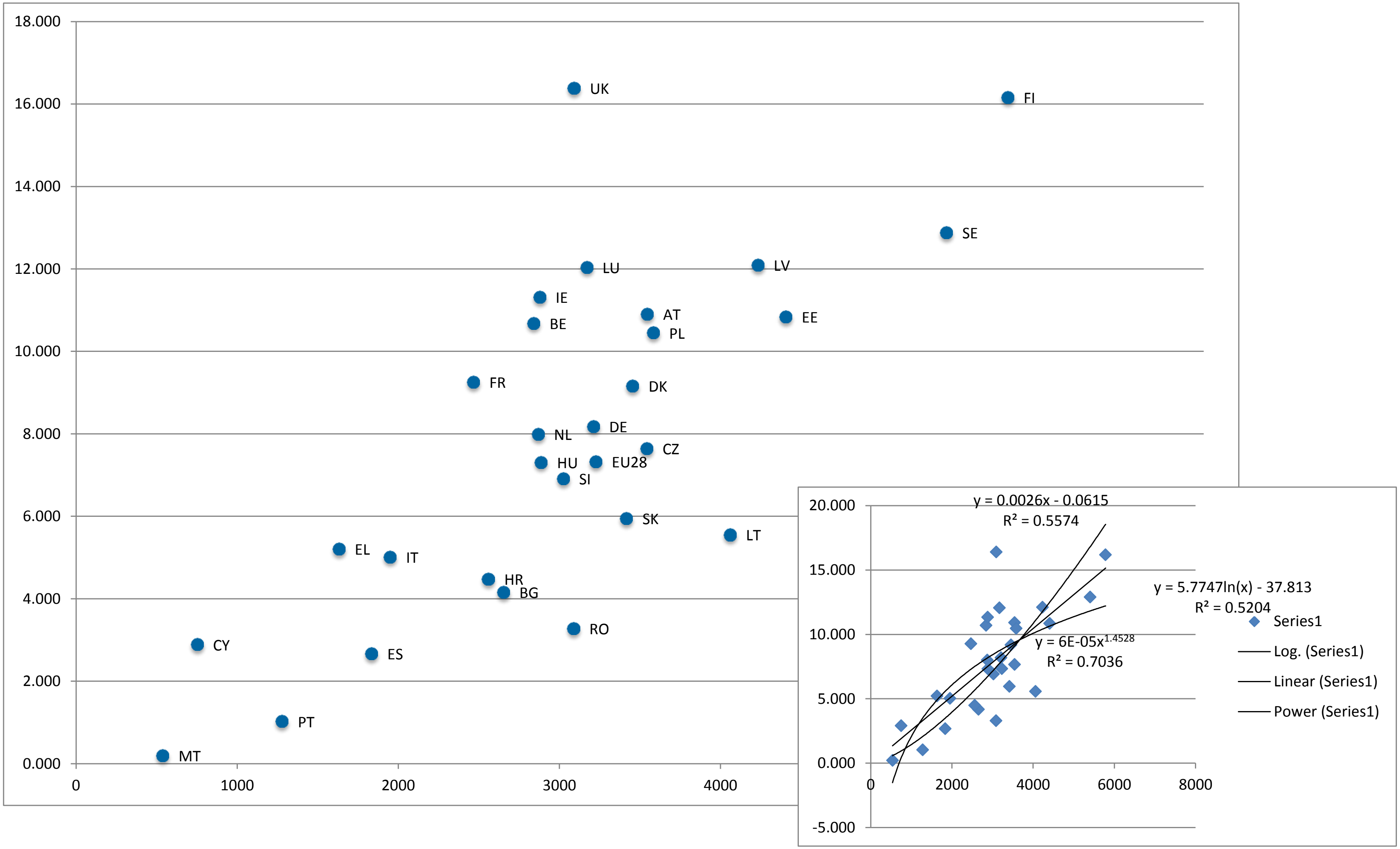
- Characterised through the combined space and water heating equipment
- Number of households equipped with solar thermal water heaters
- Different service requirements identified with explicit consideration of climate

Quantification of the contribution of non-energy equipment factors in meeting the total space heating comfort levels

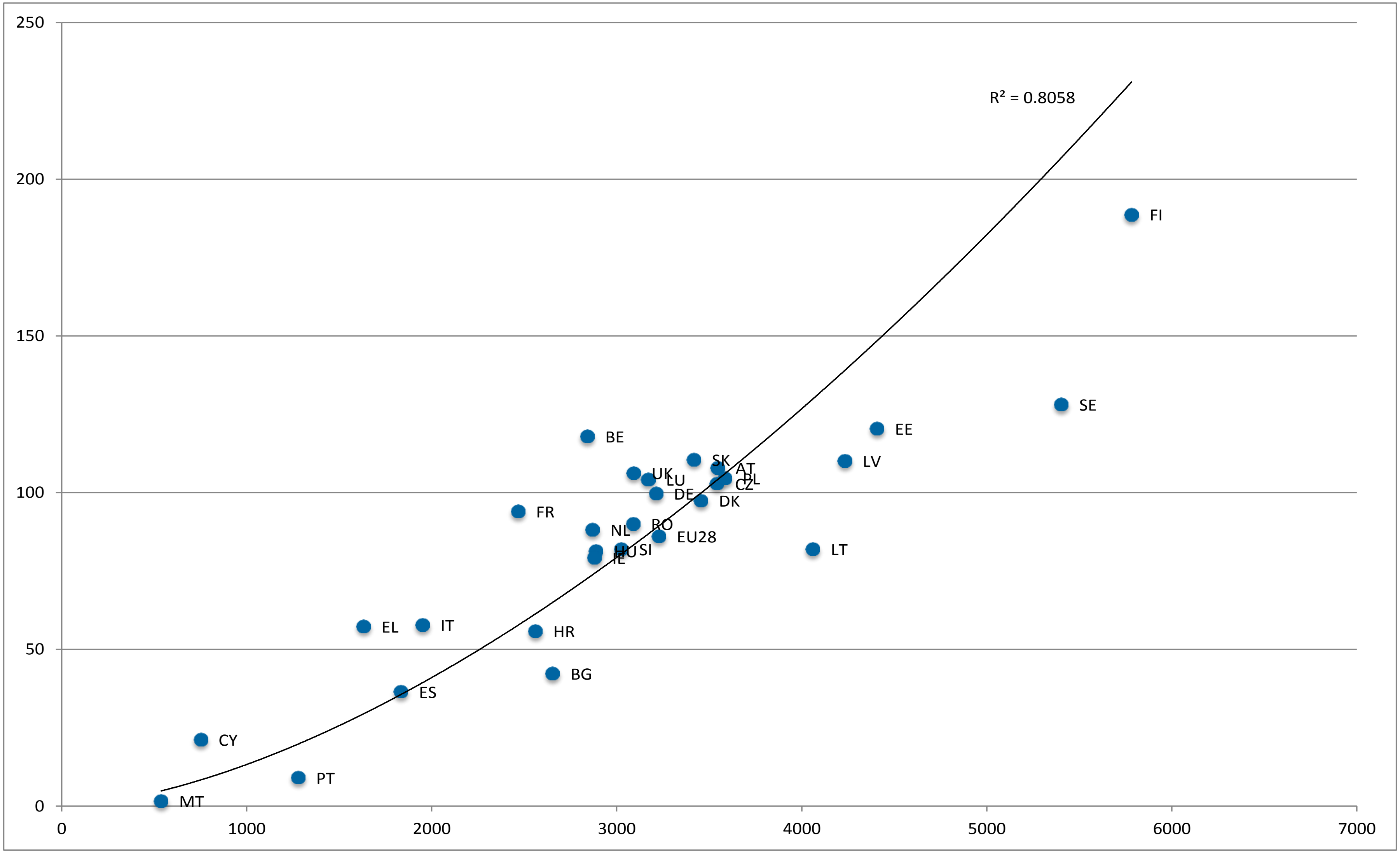
Identification of heat transfer coefficient of the building shell ('u-value')

- distribution of different building types
- u-values of building's components
- develops dynamically (renovation rate and thermal properties of new buildings)

ENERGY USE FOR SPACE HEATING PER DWELLING (KWH/DWELLING) OVER DEGREE-DAYS IN 2010

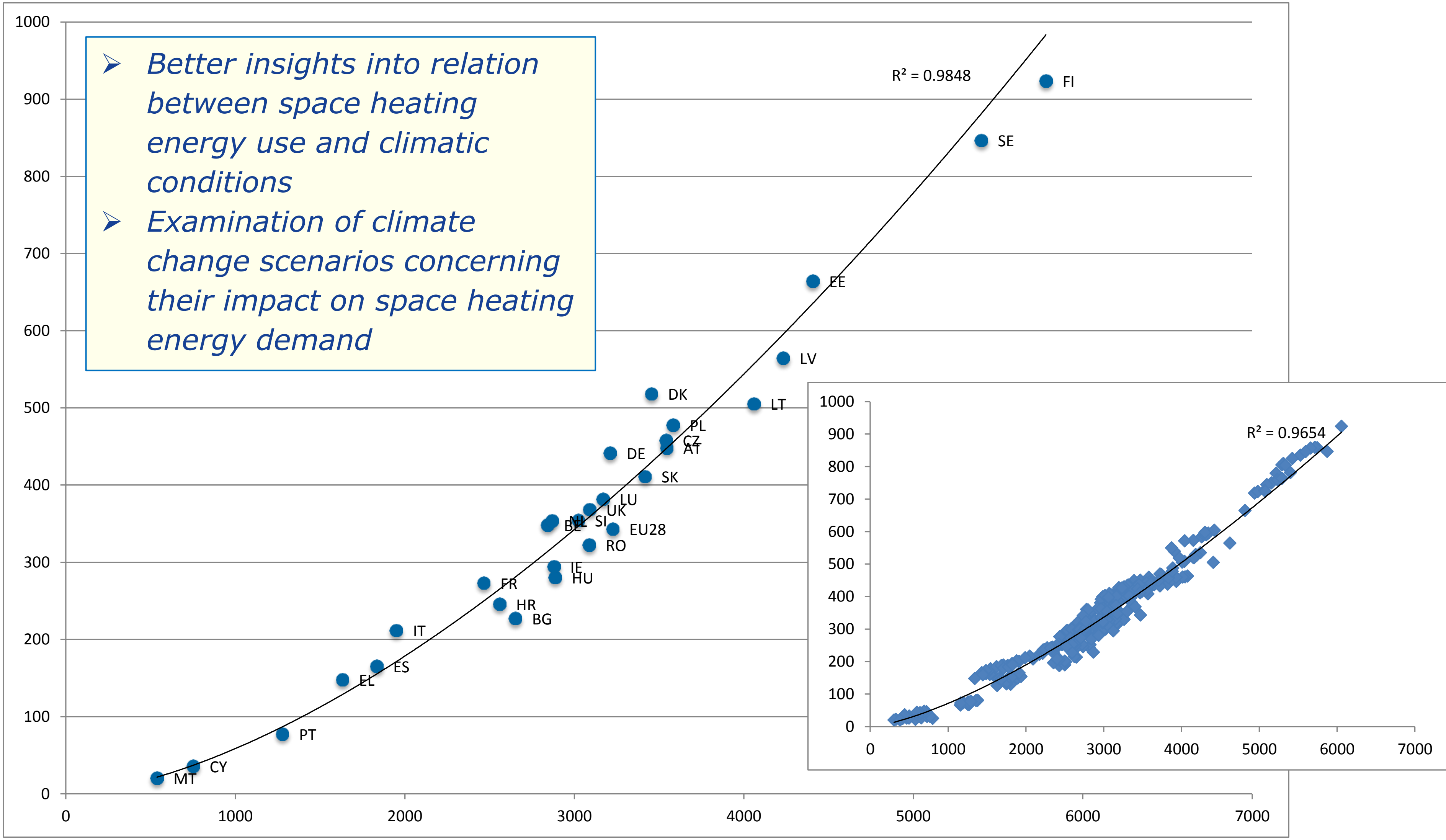


ENERGY USE FOR SPACE HEATING PER M^2 (KWH/M^2) FOR COUNTRY SPECIFIC WEATHER CONDITIONS OVER DEGREE-DAYS IN 2010



European Commission

TOTAL SPACE HEATING COMFORT LEVEL PER M^2 (KWH/M^2) FOR COUNTRY SPECIFIC WEATHER CONDITIONS OVER DEGREE-DAYS



- *Better insights into relation between space heating energy use and climatic conditions*
- *Examination of climate change scenarios concerning their impact on space heating energy demand*

RESIDENTIAL AND SERVICES

Specific electricity uses characterised at the level of the unit

- appliance
- representative electric device (e.g. ICT equipment)

Decomposition to reflect the different drivers of energy consumption

- Operating hours
- Technical characteristics (Wattage)
- Penetration factor

Washing machine	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Consumption per household (kWh)	174.5	169.9	168.8	168.5	168.3	168.9	169.1	168.9	167.8	166.6	165.4
W per appliance (in average operating mode)	490.1	447.9	429.0	411.3	394.7	379.1	364.7	351.3	338.9	327.0	315.7
Operating hours per appliance	481.0	503.8	512.9	524.5	535.7	547.5	558.5	569.8	580.9	591.5	603.0
Penetration factor (appl. per household)	0.740	0.753	0.767	0.781	0.796	0.814	0.830	0.844	0.853	0.861	0.869

Preparatory studies under 'Eco-design of energy using products regulation' taken into consideration and matched at the EU level

INDUSTRY

Decomposition ***tailor-made*** for every Member State to account for specific characteristics

- Quantification of *structural* and *production* related differences across MS
  - Distinction between technical and structural differences
  - Explicit quantification of "physical output" equivalent for sectors with diverse products
- Country-specific production options (in order to match EUROSTAT)

Quantification of ***energy service requirements per unit of output***

- Installed capacities of energy using equipment
- Explicit techno-economic characteristics, dynamically evolving
- Differentiation between product and energy equipment efficiencies
- Operation of the equipment (rate of use)

Full consistency between energy (EUROSTAT), production statistics (USGS, UN etc.) and sector-specific technical studies

TRANSPORT

Representative "vehicle" configuration

- Explicit techno-economic characteristics (dynamically evolving over time)
- Activity expressed in km driven

  in aviation, further distinction into number of flights and flight length
- Vehicle's load factor

Identification of the stock of vehicles by technology type

Enhanced breakdown by transport mode

- Split of aviation activity between domestic, intra- and extra-EU (estimate)
  - freight aviation (intra- and extra-EU)
  - better match of scope of EU-ETS
  - captures differences in trip lengths, plane type and related fuel consumption
- Split of inland navigation in domestic coastal sea shipping and inland waterways
- Bunkers treated as a transport mode (distinction between intra- and extra-EU)

Full consistency between EUROSTAT energy and activity statistics

- Use of the newly available very detailed EUROSTAT statistics
- Territoriality principle

POWER GENERATION

Full picture of existing and under construction **stock** at *unit level*

- EPIC database
- Data crosschecked on a unit by unit level
- Consistent with EUROSTAT, EURELECTRIC and EUROBSERV'ER

500 000 power plant units in 2010

- 15 000 thermal power plant units
- 145 nuclear power plant units
- 76 000 wind turbine units
  - out of which 1150 off-shore
- 393 000 solar PV
  - out of which 293 000 with an average size of 22.1 kW
- 14 000 hydro units
  - Out of which 1 560 reservoir units
- 460 pumped storage units
- 47 geothermal
- 18 solar thermal
- 25 tidal/wave units

POWER GENERATION

Power plant stock (installed and under construction) disaggregated at the level of units by

- Fuel type
- Technology
- Electricity-only and cogeneration plants
- (CCS)
- up to four typical size classes
    - Flexible classification
    - Number of units
    - Average unit size
        - variable on an annual basis
        - reflecting commissioning and decommissioning of units
    - Explicit net & gross capacities

272 power plant types

Consistent decomposition of historical data on energy consumption and electricity/steam production

- CHP electricity
- Co-firing contribution explicitly quantified

ENERGY AND CO_2 BALANCES

JRC-IDEES provides a file that corresponds to EUROSTAT energy balances

- Easy to handle file in excel format
    - Fuel specific and sector specific versions available
- Minor inconsistencies corrected
    - Breaks in Member States time series
    - Discrepancies relative to activity data
    - Allocation of unspecified energy consumption to best match sectors

The corresponding CO_2 emissions balances are also produced

- CO_2 emissions factors in line with Commission decision 2007/589/EC
- Co-firing contribution explicitly quantified

FINAL REMARKS

The database provides a ***detailed decomposition*** of energy use by sector combining

- historical data series (statistics) and
- (generic) structural parameters derived from studies, projects and surveys

in a consistent manner

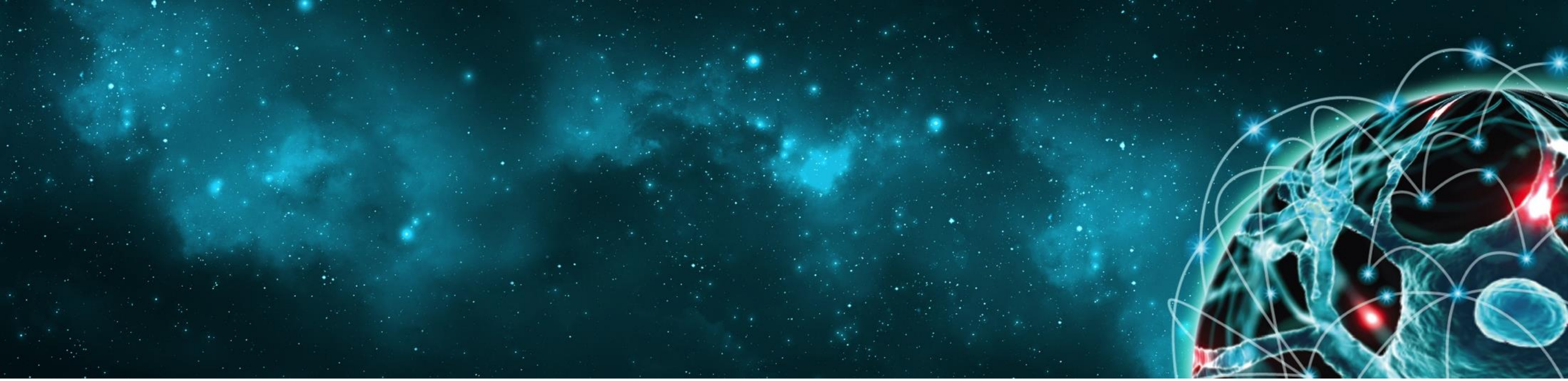
The bulk of the figures in the database are ***own estimates***

alternative quantifications of structural parameters can provide equivalently valid decompositions of data

The database can serve as a ***reference point*** both for the analysis of past trends as well as for energy modelling exercises for the future

- it quantifies the characteristics of the energy (and non-energy related) equipment in use
- it identifies different drivers and provides insights on their role by sector
- it defines a common (and flexible) basis for the EU energy system analysis

*Open access allows for improvements through a **consultation process** involving Member States experts, Stakeholders, and Academia*



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POTEnCIA

Scenario design and interactions with MS

Seville, 01/03/2016

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*Joint
Research
Centre*

POTEnCIA:

Policy
Oriented
Tool for
Energy and
Climate change
Impact
Assessment

ANALYSING POLICIES WITH POTENCIA

POTEnCIA is used to perform *comparative analysis of scenarios*

- The projections do not form forecasts (statements of what will most likely happen)
- They act as an assessment of what might be the impact of a given specific set of assumptions with respect to a plausible central ("reference") scenario
  - *Macroeconomic and demographic*

    Linking to the MAGE and GEM-E3 models; taking into account the DG-ECFIN ageing population report

    EUROSTAT projections for demographic assumptions
  - *International and/or national context for fuel prices and resources availability*

    Linking to POLES model for international fuel prices and depletable resources availability

    Renewable potentials and cost curves from GREEN-X, JRC-IET studies, (GLOBIOM, CAPRI)
  - *Technology futures*

    Linking to POLES model for power generation technologies

    JRC-SETIS technology maps and sectoral roadmaps
  - *Policy assumptions*

Main assumptions are defined in collaboration with the partner policy DGs

ANALYSING POLICIES WITH POTENCIA

The ***formulation*** and the ***methodological characteristics*** of the tool also play a significant role

Structure and characteristics of the energy system

- *JRC-IDEES database*

Behavioural parameterisation:

- exogenous market acceptance factors,
- future of technologies,
- elasticities of substitution

- *Evidence based*
- *Linked to the development of the central scenario*
- *Common across EU Member States (with limited exemptions that reflect country specificities)*

These characteristics remain unchanged across scenarios

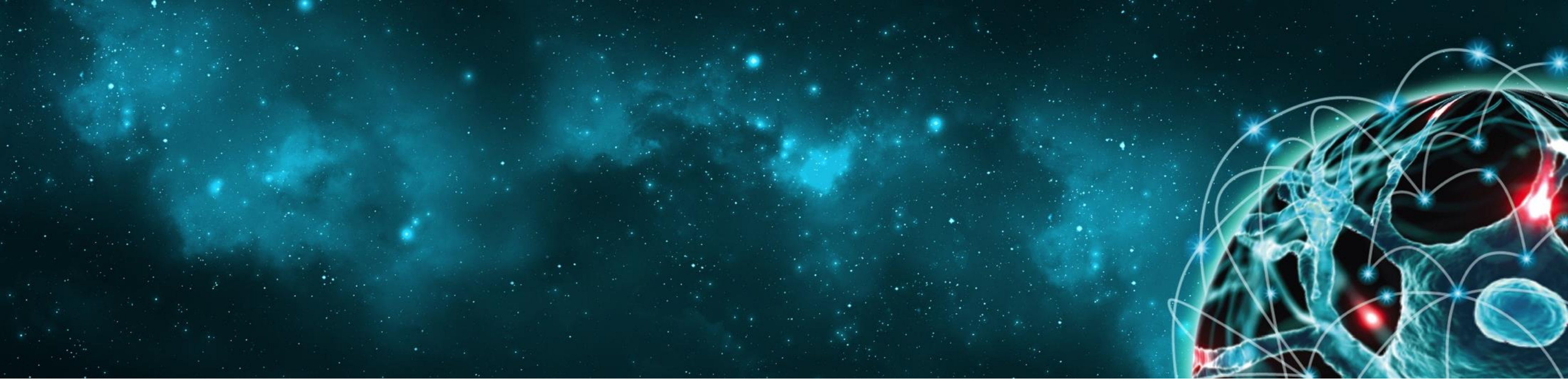
- *However, the model mechanisms ensure possible behavioural responses to prevailing scenario assumptions*

ANALYSING POLICIES WITH POTENCIA

The development of the central scenario involves continuous ***interactions with Member States***

- decomposition of historical data (validation of the JRC-IDEES database)
- incorporation of country specific policies in place
- inclusion of on-going investments
- reflection of envisaged evolution of national energy systems in a European wide context

Partners policy DGs are foreseen to be actively involved in the process.



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JRC Mission

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